1996-12

Contract administration organization: a case study of the U.S. Marine Corps Advanced Amphibious Assault Vehicle program

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THESIS

PROTOTYPE SUPERVISORY AND SUMMARY DISPLAYS FOR THE ADVANCED TOMAHAWK WEAPON CONTROL SYSTEM (ATWCS)

by

Matthew Guy Moore

March, 1996

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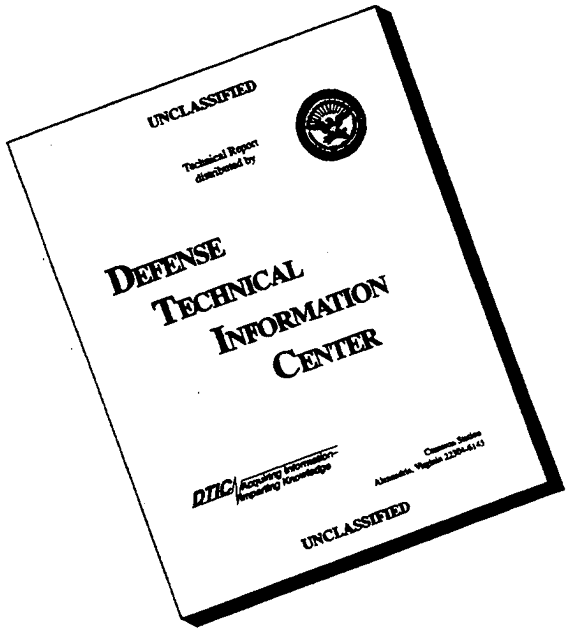

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
March 1996

3. REPORT TYPE AND DATES COVERED
Master's Thesis

4. TITLE AND SUBTITLE **PROTOTYPE SUPERVISORY AND SUMMARY DISPLAYS FOR THE ADVANCED TOMAHAWK WEAPON CONTROL SYSTEM (ATWCS)**

5. FUNDING NUMBERS

6. AUTHOR(S) Moore, Matthew G.

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(maximum 200 words)* The problem addressed in this research is the need for supervisory or system summary displays for the Advanced Tomahawk Weapons Control System (ATWCS). These displays are needed to accurately depict the current system state and weapon status in order to aid strike supervisory personnel in making correct and timely decisions. This research examined the problem in the context of designing a set of graphical displays that extracts information relevant to the strike supervisor from ATWCS and displays it in a manner that allows both rapid and accurate interpretation.

The approach used to solve the problem progressed in four distinct phases. The first phase, Requirements Analysis, consisted of gathering system requirements through interviews with U.S. Navy officers who have experience as strike warfare supervisors. In the second phase, an initial design was produced using Century Computing's rapid prototyping tool TAE Plus Workbench™. The third phase involved the heuristic and guideline evaluation of the prototype based on accepted user interface design principles and ATWCS user interface requirement specifications. This evaluation produced a second iteration prototype that was used in the final phase, Usability Testing. The prototype was tested by U.S. Navy Officers with Tomahawk strike experience and test results were recorded. Changes were then made to the prototype to correct usability problems discovered by the user testing, yielding a third iteration prototype.

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14. SUBJECT TERMS ATWCS, Human-Computer Interface (HCI) design, Usability Engineering

15. NUMBER OF PAGES 86

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18 298-102

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PROTOTYPE SUPERVISORY AND SUMMARY DISPLAYS FOR THE ADVANCED TOMAHAWK WEAPON CONTROL SYSTEM (ATWCS)

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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN COMPUTER SCIENCE

from the

NAVAL POSTGRADUATE SCHOOL
March 1996

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LIST OF ACRONYMS

ATWCS	Advanced Tomahawk Weapon Control System
CCOI	Critical Contact of Interest
C & D	Command and Decision
CO	Commanding Officer
COI	Contact of Interest
DBM	Database Manager
ECO	Engagement Control Officer
EP	Engagement Planner
EPC	Engagement Planning Console
HCI	Human-Computer Interface
INS	Inertial Navigation System
LC	Launch Controller
LCU	Launch Control Unit
OOD	Officer of the Deck
OSF	Open Software Foundation
OSV	On-screen Variable Action Button
OTCIXS	Officer in Tactical Command Information Exchange System
SSTWC	Surface Strike Warfare Coordinator
TAO	Tactical Action Officer
TLAM	Tomahawk Land Attack Missile
TOL	Time of Launch
TOT	Time on Target
TUL	Time Until Launch
VAB	Variable Action Button
VLS	Vertical Launching System
WCS	Weapon Control System

ACKNOWLEDGEMENT

I would like to thank my wife, Melissa, for her understanding during the past two years. But most of all, I want to thank her for our daughter, Mallory, whose entrance into our lives has made it all worth while.

I. INTRODUCTION

A. BACKGROUND

Of the 124 surface combatant ships currently active in the U.S. Navy, 63 are equipped to launch Tomahawk cruise missiles (Sharp, 1995). Of the ten ships that are planned for construction through Fiscal Year 1996, eight will be equipped to launch Tomahawk cruise missiles (Sharp, 1995). From these statistics one can see that Tomahawk cruise missiles do and will play a large role in the U.S. Navy's operations.

Because Tomahawk missiles have the ability to strike a wide variety of targets hundreds of miles inland, they provide operational commanders with many options. Tomahawk cruise missiles can destroy targets that jeopardize flight crews, such as surface-to-air missile sites. During contingency operations, they provide a rapid reaction capability in response to a quick change in hostilities. Tomahawk is a dependable weapon that can be used to strike a wide range of targets giving operational commanders a versatile tool with which to conduct wartime operations.

Tomahawk land attack cruise missiles (TLAMs) are complex missiles with equally complex firing procedures. Because of this complexity, strike watch teams typically have five members: A Database Manager (DBM), Engagement Planner (EP), two Launch Controllers (LCs) and an Engagement Control Officer (ECO), also called the Surface Strike Warfare Coordinator (SSTWC) on some ships. All watch team members, except the ECO, are seated at an Advanced Tomahawk Weapon Control System (ATWCS) console at which they carry out the tasks associated with their position. ATWCS is the shipboard system that encapsulates all the control functions necessary to launch TLAMs.

The ECO, acting as the overall strike supervisor, provides guidance to each of the strike team watchstanders based on current mission requirements and the tactical situation. The ECO also advises the Commanding Officer (CO), Tactical Action Officer (TAO) and Officer of the Deck (OOD) on all matters concerning a TLAM strike. The ECO's duties include keeping the CO and TAO informed of the mission status. This consists of information such as any new TLAM mission tasking received, the progress of TLAM missile warm-up, the current operational status of the system, etc. The ECO also keeps the OOD informed of launch positions and launch times.

To effectively perform his duties and make proper decisions, the ECO needs access to a variety of information available from the weapon control system. Currently, there is no single resource in ATWCS that provides this information. Instead, the information is scattered throughout the various subsystems: database management, engagement planning and launch control. As a result, the ECO must frequently interrupt console operator's tasks to receive updates to time critical information.

To further complicate matters, Tomahawk mission tasking is usually quite intense, requiring the ECO to track multiple engagements, each with multiple missiles, simultaneously. This fact is supported by historical data from Operation Desert Storm, the first use of Tomahawk cruise missiles in combat (Office of the CNO, 1991). Cohen (1993) shows that during the first day of hostilities, 122 Tomahawk land attack missiles (TLAMs) were fired with a steady decline in tasking throughout the first week. In all, 288 TLAMs were fired from just 16 ships and two submarines with the USS FIFE (DD 991) launching 58 missiles during the course of the war (Office of the CNO, 1991). The success of TLAM in Desert Storm has made it the weapon of choice for disrupting enemy operations and hitting targets when aircraft are either not available or unable to fly due to heavy anti-air defenses. More recently, the USS NORMANDY (CG 61) launched 13 TLAMs into Bosnia on September 10, 1995 to destroy an air defense site (*Surface Warfare*, 1995). Based on this historical data, it is a reasonable assumption that future conflicts will see the extensive use of TLAM early in the hostilities. Such tasking will require ECOs to keep track of multiple missions whose launches must be timed to the second to meet strike objectives.

The aim of this research is to provide the ECO with a tool to reduce the task load associated with supervising a TLAM strike. This will be done by using usability engineering methods to design graphical displays that give the ECO a single source of necessary information. These summary displays will be located on a small LCD video monitor attached to the top of the standard ATWCS monitor.

B. OBJECTIVES

The purpose of this thesis is to present a series of prototype graphical displays for ATWCS that are tailored for use by strike team supervisors. This research employs usability engineering methods to determine what information strike supervisors typically need throughout the course of an engagement and the best way to display it. The product of this research is a set of graphical displays that will allow rapid and accurate assimilation of system data by strike supervisors.

There are several objectives to reach before achieving the final goal of a set of prototype displays. The first objective is to determine exactly what information the ECO needs to perform his duties. This information is analyzed to determine the level of detail required by the ECO. Further, the information is prioritized to better determine how it is to be presented to the ECO. The second objective is the production of a first iteration prototype that not only displays the information accurately, but allows for rapid assimilation. This prototype is designed within the established framework of JCM-2154, the ATWCS Human-Computer Interface Requirements Specification, and conforms to general interface design guidelines. As a further requirement, the displays must fit on the size-limited secondary screen. The final, and perhaps most important, objective is that the summary displays be simple to use and understand. This objective is met using both heuristic evaluation and usability testing with experienced ECOs to reveal usability problems and make corrections to the prototype.

C. INTERFACE ENVIRONMENT

1. Hardware Environment

The summary displays, hereafter called ECO displays, presented in this thesis must fit on the limited screen space of the ATWCS console's secondary LCD screen. The overall resolution of the screen is 640 pixels by 480 pixels; however, required interface elements reduce the usable screen space to 631 by 395 pixels. The ECO display's window frame further reduces the application area to 611 by 356 pixels. Figure 1 shows the layout of the secondary screen along with its associated dimensions.

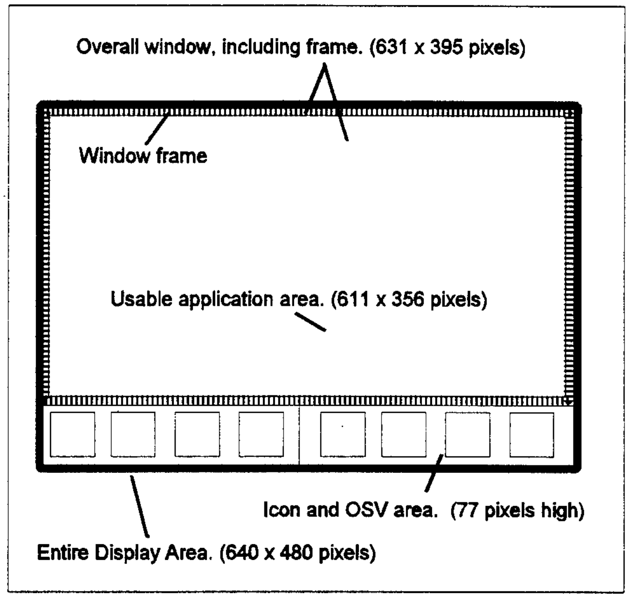

Figure 1. Secondary Screen Layout.

JCM-2154 states that supervisory information should appear on the upper display. Although the secondary screen's usable application area is very small, its physical location makes it the ideal place for displays intended for ECOs. Due to the nature of the ECO's duties and the lack of a dedicated console for his use, the ECO typically remains standing behind the watch team members throughout the strike. The elevated position of the secondary screen allows information to be viewed by the ECO without having to lean over and interrupt a watchteam member.

2. Software Environment

The ECO displays are designed as an addition to an existing system. As such, they must strictly adhere to the established HCI guidelines and requirements for the parent system. JCM-2154 is the governing document for all ATWCS HCI requirements. It defines both the appearance and the behavior of the interface for ATWCS.

ATWCS uses the UNIX operating system, X Window System window manager and the Open Software Foundation (OSF) Motif graphical user interface widget set. The X Window System, or X, provides functions for creating and managing windows as well as for drawing in these windows. Motif is a set of preconstructed user interface elements, called widgets, that provides a high level application interface with X. Motif provides a common look and feel to application programs that use it, providing consistency between the interfaces of different applications (Brain, 1992). In other words, a Motif button in one application looks and behaves just like a Motif button in another. JCM-2154 further defines how each Motif interface element should appear and behave within the framework of ATWCS.

D. INTERFACE DESIGN METHODOLOGY

The methodology used to design the ECO displays is adapted from the usability life cycle presented in Nielsen (1993). Since the displays were designed as an addition to an existing system, many steps of the life cycle had already been performed by the parent system's developers, resulting in JCM-2154, a very detailed HCI requirements specification. The remaining steps that were needed to design the ECO displays were carried out in four phases: requirements analysis, design and prototyping, heuristic and guideline evaluation and usability testing.

The methodology used results in an iterative design process that is focused on the needs of the user. The first two phases extract the user's requirements and transform them into an initial prototype designed to conform to existing interface requirements. Well-defined sets of heuristics and guidelines ensure the interface conforms with sound interface design principles to reveal obvious usability problems. Usability testing subjects the prototype to a final evaluation conducted by the user. Problems found in testing are corrected to yield a third iteration prototype.

E. OUTLINE

Each of the next four chapters of this thesis present a different phase of the methodology. The issues, detailed methods and results of each phase are presented. At the end of Chapters III, IV and V, the resulting interface design will be presented. The final chapter will include conclusions and recommendations about both the design method used and the resulting product.

II. REQUIREMENTS ANALYSIS

The goals of requirements analysis are to define the purpose of a proposed software system and determine any constraints on its development (Berzins and Luqi, 1991). When designing a user interface, requirements analysis also entails determining the user tasks that the interface must support. User tasks and needs are defined in terms of the users and their environment, with no reference to how the system will support those tasks or meet those needs (Lewis and Rieman, 1993). Simply put, requirements analysis specifies what a piece of software is supposed to do, not how it is supposed to do it.

This chapter specifies the requirements for the Engagement Control Officer (ECO) displays. These requirements include what information should be on the displays and any constraints on the displays. The informational requirements are divided based on a taxonomy that considers each piece of information's importance to the ECO during the course of a Tomahawk Land Attack Missile (TLAM) strike.

A. REQUIREMENTS SOLICITATION

To best determine what information would benefit an ECO during a strike, 15 U.S. Navy Surface Warfare Officers were questioned. Each officer has ECO and Tactical Action Officer (TAO) experience from different Tomahawk Land Attack Missile (TLAM)-capable platforms. During initial contact, the concept of the ECO displays was explained. Because ATWCS is not yet on board most TLAM-capable ships, interviewees were given a description of the hardware for the ATWCS console. Each officer was then asked to list the information they required during a TLAM strike; particularly, any information that requires interrupting a console operator to obtain. Subsequent communication involved questioning the interviewees about their replies to further narrow their specific requirements.

All but one interviewee relied on recent experience with TLAM operations to determine the information they would find useful. The remaining officer, currently serving as Strike Warfare Officer on board a destroyer, conducted several strike simulations in order to determine the information he would find helpful. During these simulations he noted the information that he continually required and that which his chain of command requested.

To ensure the officers not assigned to ships accurately recalled the information needed during a TLAM strike, their requirements were compared to those found during the simulations. Since the requirements from both sources coincide, those based on memory alone are considered accurate. Also, as all of the requirements were listed by at least two officers, the requirements are the information required during a TLAM strike.

B. REQUIREMENT TAXONOMY

To better decide how to display the information on the ECO displays, the notion that one piece of information can be more important than another must be introduced. If the informational requirements are not prioritized there is a chance that a critical piece of information might not be displayed prominently for the ECO. Likewise, a piece of information that is not critical might distract the ECO due to its placement, text size, etc.

Each requirement is placed into one of three categories having the following criteria:

- Critical - Constantly or frequently updated information that the ECO needs repeatedly. Critical information should be visible at all times.
- Summary - The information in this category, when viewed together, depicts the overall system status. Summary information should be displayed together on a single screen.
- Detail - This information provides the details needed by the ECO to perform his duties. Detail information can be spread out over several screens but should be grouped together with similar information where possible.

C. REQUIREMENTS

1. Informational Requirements

Figure 2 lists the informational requirements resulting from requirements elicitation and divides them according to the taxonomy discussed previously. The requirements are divided based on comments from the interviewees.

CRITICAL

- Time Until Launch (TUL) of the next missile to be launched
  Course and speed to arrive at launch point of next missile to be launched at its Time of Launch (TOL)
- The status of Officer In Tactical Command Information Exchange System (OTCIXS) and the time since data was last received (time late).
- System mode (Training/Tactical)
- Overall Vertical Launching System (VLS) status (Fault/No Fault)
- Bearing, range and ATWCS track number of nearest Critical Contact of Interest (CCOI)

SUMMARY

- Maximum salvo available of each TLAM variant
- For the next plan to be launched:
  - Plan number
  - Plan status
  - TUL
  - Time on Target (TOT)
  - TOL
  - Missile alignment status of the last missile
  - Plan Salvo
  - Review Required (Yes/No)
- Launch Control Unit (LCU) configuration and status
- Status of Command and Decision (C&D) interface
- Status of Inertial Navigation System (INS) and its alignment (Forward/Aft)
- Launchers authorized and selected
- VLSs authorized
- VLS controlling Weapon Control System (WCS)
- VLS mode (Tactical/Simulated)
- VLS State
- VLS inventory status
- VLS Launch Enabled
- Engagement Planning Console (EPC) mode
- Launch Control (LC) mode

Figure 2. Informational Requirements for ECO Displays.

DETAIL

- For each active TLAM plan:
  - Plan Number
  - Plan Status
  - Plan Order
  - Time of Launch (TOL)
  - TUL
  - Time on Target (TOT)
  - Missile alignment status of last missile
  - Plan Salvo, Ready Spare and Backup (# of missiles)
  - Number of missiles selected
  - Review Required (Yes/No)
  - True and Relative Bearing of missile departure
  - In launch basket? (Yes/No)
  - Bearing, and range to launch point
  - Required course and speed to arrive at launch point at TOL
- For each missile assigned to a plan:
  - Cell number
  - Missile type
  - Associate plan number
  - Launch Side (Port/Starboard)
  - Alignment status
  - Booster status
  - Missile status
  - TUL
- For each VLS:
  - Missile type in each cell
  - Plan number of cells/missiles assigned to a plan
  - Any modules with faults
  - Location of any inoperable missiles
  - Location of missiles being aligned
  - Location of missiles that have completed alignment
- Bearing, range, course and speed of all COIs/CCOIs

(Figure 2 continued.) Informational Requirements for ECO Displays.

2. Interface Requirements and Constraints

The ECO Displays must conform to the requirements listed in JCM-2154. Appendix B of JCM-2154 contains a checklist that can be used to ensure compliance with the requirements specification. In addition to the requirements listed in that appendix, the interface is constrained by the following physical characteristics:

- The displays must fit in the secondary LCD screen.
- The overall window size shall not exceed 631 by 395 pixels, including window frame.
- The application area of the window shall not exceed 611 by 356 pixels.
- The ECO displays shall use a viewing distance of 26 inches. Based on JCM-2154 requirements the font shall be Helvetica with a minimum of 13 point bold and a maximum of 24 point with a preferred size of 18 points.

D. CONCLUSION

This chapter lists the requirements that fleet ECOs need to conduct a TLAM strike. These user requirements drive the design of the ECO displays. The displays must incorporate all the requirements in order to meet the needs of the user. The design must also take into account the requirement taxonomy and the limited display area of the secondary screen.

III. INTERFACE DESIGN

A. DESIGN CONSIDERATIONS

As with any interface, there are many issues influencing the design of the Engagement Control Officer (ECO) displays. When designing a user interface, the designer must always keep in mind the function of the interface. The function of the ECO displays is to display required information to the ECO during a Tomahawk Land Attack Missile (TLAM) strike. This information must be displayed in such a way that the ECO can interpret it accurately and quickly.

> If the system does not present the information that the user needs, or presents it in an unusable or confusing manner, the user may decide not to use the system..., or the user's ability to perform the necessary task may be sharply degraded (Tullis, 1988).

The small size of the secondary screen is also a primary consideration in the design of the ECO displays. All the required information must fit in the limited space allowed on the secondary screen. This requires that information be displayed as tersely as possible without a loss of information. The information must be both concise and complete to prevent inaccurate interpretation by the ECO.

Mayhew (1992) states "user interface design is a matter of compromise and trade-off." Often the goals of accurate and rapid assimilation and minimum screen use seem mutually exclusive. In such cases, a compromise must be reached that allows the most complete data in the smallest screen space possible.

The ATWCS Human Computer Interface (HCI) Requirements Specification, JCM-2154, clearly defines the framework to which the ECO displays must conform. This interface framework must also be considered when designing the ECO displays. Although designing an interface under such strict standards may seem restrictive, it provides several advantages. Interface standards provide guidelines for the operation and visual presentation of interface elements ensuring that a button "looks and feels" the same throughout an application. These same interface elements provide standard methods of interaction. (Lewis and Rieman, 1994) For example, to select an option from a list of mutually exclusive list is often done using a set of radio buttons (Open Software Foundation, 1993). Designing to meet an existing standard allows the designer to concentrate on the best way to present the interface rather than the details of how interface elements must interact with the user (Lewis and Rieman, 1994).

B. PROTOTYPING

According to Nielsen (1993), the idea behind prototyping is to quickly and cheaply develop something that can be tested with real users. In the case of a user interface, prototypes allow interactive user testing to find usability problems before implementation. Typically, an interface prototype is tested and modified iteratively as usability problems are uncovered and corrected. This strategy is effective because it is normally less expensive and time consuming to correct problems during the prototyping phase than after a system has been implemented.

To save cost and time, prototypes are a scaled down versions of the final system, lacking either features or functionality of the full system. These two dimensions of prototyping are described in Nielsen (1993) as vertical and horizontal prototypes. A vertical prototype is one which fully implements only selected features of a system. For example, a vertical prototype of an address book program might implement data entry and retrieval with real data but no search capability. Vertical prototypes can only be used to test portions of a system, although this testing will be under real circumstances with real user tasks. A prototype that has a reduced level of functionality is called a horizontal prototype. A horizontal prototype is a surface layer that includes the entire user interface but has no underlying functionality. (Nielsen, 1993) A horizontal prototype of an address book program would include all data entry screens, search dialog boxes, etc., but have no ability to store or retrieve data.

Prototypes can implemented in several ways. An interface design could be prototyped by using paper mock-ups. A developer might design the prototype of a future system on a platform different from the final system's target environment. A prototype could also be constructed using a generalized scripting language such as shell scripts rather than a true programming language. There also exist many tools designed specifically for prototyping. (Nielsen, 1993) Each of these methods have their own advantages and disadvantages which are discussed fully in Nielsen (1993).

The ECO displays are a horizontal prototype constructed with the aid of TAE Plus Workbench™, a rapid prototyping tool from Century Computing. TAE Plus Workbench™ allows a developer to visually construct an interface and then provide limited functionality by using a scripting language. The interface can then be rehearsed in real time during development. Another advantage of this tool is that it can generate high level language code, such as C or Ada, to implement the interface, shortening development time. TAE Plus Workbench™ does have a disadvantage in that it does not fully support some functionality found in X-Windows and Motif.

TAE Plus Workbench™ is the development tool for the ECO displays for several reasons. First, its visual nature allows it to display the application area and interface objects of the ECO displays in their true size. This is especially important because the limited space available to the displays must be utilized effectively. Second, TAE Plus Workbench™ allows the interface to be rehearsed interactively. This allows users to actually see how the ECO displays look and feel during user testing without having to write application code. Finally, the tool's availability and compatibility with JCM-2154 standards make it an ideal development environment.

C. OVERALL INTERFACE CONCEPT

Good interface design is not a matter of applying a set of rules or algorithms to achieve a usable interface. As discussed in Mayhew (1992), there are many principles for designing a good interface. However, just knowing these principles is not enough to ensure a usable interface. A good interface comes from knowing the user, his tasks and his goals. The design of the ECO displays is driven by the nature and the volume of the information that it must present.

Obviously, there are many ways to implement the ECO displays, but one characteristic will be shared by any design. Because the amount of information required by the ECO is quite large, it is apparent that any design will have to use multiple screens, or pages, to fit the information on the secondary screen. This requires a navigation method to switch between the display's pages.

The nature of the information to be displayed greatly influences the conceptual design. Critical information must be displayed at all times implying that some portion of the ECO displays be constantly visible. Summary information must be grouped together coherently. This suggests that all the summary information be displayed on the same page. Detail information should be grouped together, indicating the need for pages that contain similar information.

To account for the various categories of information that must be displayed the following window layout scheme is used. The basic window of the displays is sized to the maximum size for the secondary screen of 631 by 395 pixels, making the application area 611 by 356 pixels. To provide an area that is constantly visible, the top 45 pixels of the application area will remain static. All critical information will appear in this permanent status bar. The remaining application area below the status bar will be used for summary and detail information. All summary information will appear on a single summary page, while detail information will be grouped together and placed on a series of several displays.

As mentioned previously, a navigation method is required to view the various pages of the ECO display. Rather than provide a navigation mechanism that would use a portion of the application area, such as tabs, the On-Screen Variable Action Buttons (OSVs) already present on the secondary screen are used. OSVs are push buttons whose changing labels can simulate a menu hierarchy. Their placement adjacent to the ECO display's window and the fact they use no additional application area make them an ideal choice. The functionality of OSVs is fully described in JCM-2154.

D. DESIGN DETAILS

As discussed previously, the amount of information to be presented requires the ECO displays be divided into several pages. Based on the nature of the informational requirements, the displays are split into the following five pages: ECO Summary, COI/CCOIs, Forward VLS Status, Aft VLS Status and Plan Status. At the top of every page is a status bar that contains all the critical information listed in the informational requirements. To navigate between these pages, the OSVs are configured as shown below in Figure 3.

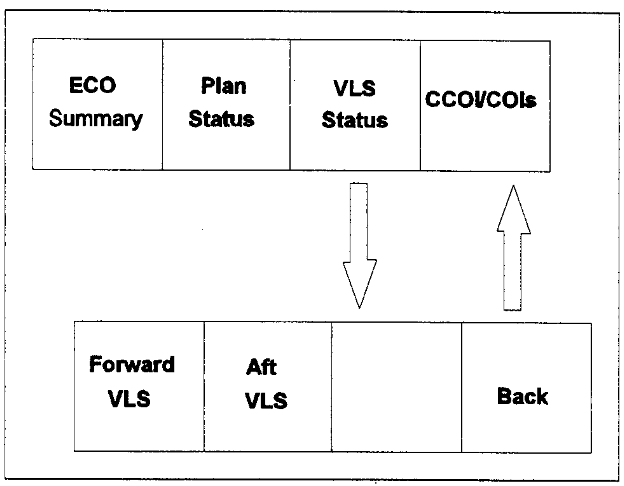

Figure 3. OSV Configuration.

Because the main objective of the ECO displays is to present information that can be interpreted accurately and quickly, particular attention was paid to screen layout. There are literally thousands of data-display and screen design principles available to the designer, such as those in Schniederman (1992) and Mayhew (1992). Many of these guidelines are based on the work of Tullis (1988) who reviewed the results of several empirical studies of screen design. Based on the observed results of those studies, Tullis offers many general guidelines on how best to format screen displays for maximum accuracy in minimum time and space. Throughout the design of the ECO displays, the principles in Tullis (1988) are to be applied whenever possible.

E. DESIGN DECISIONS

1. Layout of Critical Information on the Status Bar

a. Alternative Approaches

The critical information could be placed on the status bar in just about any arrangement. The limited vertical size of the status bar (45 pixels) prevents grouping information in vertical columns over 2 rows high.

b. Solution and Discussion

Tullis (1988) presents several options for the sequence of data presentation. The most applicable of these in the case of the critical information is sequencing by importance. Another consideration, not included in Tullis, is the update frequency of the data.

The critical data can be divided logically as listed below:

- Next launch data:
  - TUL
  - Course and speed to launch positions
- OTCIXS information:
  - Status (up or down)
  - Time late of OTCIXS
- VLS status:
  - Forward VLS status
  - Aft VLS status
- Training Mode
- Track number, bearing and range of the nearest CCOI

One arrangement is to have four columns of two rows each, with the two single element groups making a column. Of these, the next launch data information is the most time critical, therefore it should be the first column. The OTCIXS data can be considered least critical in that the loss of the OTCIXS link will not prevent a missile launch, consequently, it should be in the last column. Of the two remaining groups, neither one has any reason to precede the other, so any arrangement of these two is acceptable.

2. Navigation Method Between Pages

a. Alternative Approaches

There are several navigation methods that would be effective for the ECO displays. These include tabbed pages, push buttons attached to the status bar, a menu bar, a pop-up menu, hot-keys and the OSVs.

b. Solution and Discussion

Of all the alternatives mentioned above only the last three do not require application area be taken away from the ECO displays. Because space is so limited, the first two alternatives are not viable options.

The OSVs are the best of the remaining three options for the following reasons:

- Hot keys, while they normally offer short cuts for experts, require a two handed operation such as Control-K. The OSVs, for all but the VLS status pages, require only a single keystroke. For the VLS status pages, two keystrokes are necessary.
- A pop-up menu requires mouse interaction within the application area of the window. Because the ECO displays are on the secondary screen, mouse interaction can be distracting to the console operator. One of the purposes for the ECO displays is to prevent interruption of the console operator's tasks, therefore a pop-up menu is not the best choice. If mouse interaction is desired, the OSVs can be pushed just like any other pushbutton.
- The OSVs' proximity to the ECO displays connect the two visually.

3. Method of Grouping Information

a. Alternative Approaches

To display many items on the same screen, it is helpful to organize them into semantically related groups (Mayhew, 1992). Because space is so limited on each page of the ECO displays, this is especially critical. To set off the groups from one another there are three options presented in Tullis (1988): white space, graphical boundaries and highlighting.

b. Solution and Discussion

Because the font used in the ECO displays is Helvetica 14 point bold as required by JCM-2154, highlighting becomes a difficult issue. To highlight an entire group would mean that quite a bit of information would have to italicized, displayed in reverse video or have the intensity changed. However, any of these techniques would only serve to clutter the display. Because of the density of information displayed on the various pages, white space alone is not sufficient to convey the visual concept of information groups. Graphical boundaries are the best option for setting apart groups of information in the ECO displays. They enable the information to be set apart without cluttering up the display or using excessive space. Although any graphical boundary might be effective, a logical choice from the programmers point of view is the X-Workspace.

Labeling of each group should be obvious and easily associated with the group. A label in a large font (24 point bold) placed near the group is sufficient.

4. OSV Hierarchy

a. Alternative Approaches

The four OSVs must allow the user to access five pages: ECO Summary, COI/CCOI, Forward VLS Status, Aft VLS Status and Plan/Missile Status. The changing labels on the OSVs allow almost any possible layout. Two possible alternatives include:

- The four OSVs are labeled to access the four pages not currently displayed. When an OSV is pressed its label changes to the last page displayed.
- Have OSVs labeled for ECO Summary, COI/CCOI and Plan/Missile Status. The final OSV is labeled VLS Status. Upon depressing VLS Status all buttons are cleared and two buttons are relabeled for Forward and Aft VLS. The display is changed after the user selects their desired launcher.

b. Solution and Discussion

The first option discussed above is not an acceptable solution because it violates the idea of consistency. Each time an OSV is pressed the label changes to the previous page displayed. This means that the order of the OSVs will change constantly. This prevents the user from remember which keys correspond to which page.

The second option is more consistent as all the first level button labels always appear in the same positions. However, it does not provide any mechanism to back out of the second level labels if the user decides not to look at a VLS launcher or hit the incorrect key.

A better option is to extend the second level of the second option discussed above. The addition of a button to return to the previous level enables the user to change his mind or back out in the case of a incorrect key press.

5. Method of Highlighting Information

a. Alternative Approaches

There are many methods to highlight information including reverse video, color, brightness or boldness, underlining and flashing (Tullis, 1988). Another method to highlight a piece of information is to increase its size relative to other information on the display.

b. Solution and Discussion

The font size requirements listed in JCM-2154 for a 26 inch viewing distance indicate that a minimum font of 13 point bold is required. To enhance readability at this distance, all text is bold. This eliminates the use of this mechanism to highlight information.

Due to the information density that is necessary to place all required information on the ECO displays, highlighting methods such as highlighting, increased brightness, small font size changes and changing font color will likely not be very effective. For a highlighting method to be effective on a very densely packed display, it must truly set the information apart from the rest of the display. This is best done with a large font change or with a combination of reverse video and color. "Two to four different character types used in consistent ways are optimal." (Mayhew, 1992) Also, evidence shows that reverse video is a very powerful search que and is useful to indicate that an item has been selected or to indicate an error field (Mayhew, 1992).

6. Labeling Conventions

a. Alternative Approaches

There are many ways to label information on the screen. Labels could be placed above or to one side of the data. The labels could be all capital letters or highlighted in some way. However the labeling is to be accomplished, "every data item on a screen should be labelled in some way." (Tullis, 1988)

b. Solution and Discussion

Labels in the ECO display will account for a lot of the screen space used, therefore some consistent method should be implemented. Such a scheme follows:

- Labels should contain both upper and lower case letters. Mixed case text is easier to read than all uppercase text. Studies show a 13% increase in reading speed for mixed case text. (Mayhew, 1992)
- If many labels appear in a column, they should be right justified. Left justified labels can lead to too much space between labels and data elements. (Tullis, 1988)
- Each label should be followed by a colon. This provides consistency among labels and identifies text as a label and not a data element.
- Labels should reflect correct user terminology. Tullis (1988) states that, based on empirical data, familiar data formats, concise wording and abbreviations should be used. More commonly, this is known as speaking the user's language (Nielsen, 1993).

There might be times when such a labelling scheme cannot be followed. This is a definite problem when dealing with large amounts of data in extremely small screen space, such as in the ECO displays. In such cases, as many of the above guidelines as possible should be used.

7. Displaying Information That Will Prevent Launch

a. Alternative Approaches

Any data that prevents launching a missile should be brought to the attention of the ECO. This requires that the information be highlighted in such a way that it is easily picked out from other data on the display. As discussed above, options include reverse video and color or increased font size.

b. Solution and Discussion

Increased font size is not a good choice for highlighting information in this case. Because of the density of the information, labels and information must be spaced close together. Increasing the font size of a piece of information may cause it to interfere with nearby data.

"Color is very effective in drawing attention." (Mayhew, 1992) It can also be used to convey status to help the user determine the nature of the message even before reading it (Mayhew, 1992). Although simply changing the color of the text would be effective, redundant coding enhances performance (Mayhew, 1992). Thus, reverse video should be used to provide redundant coding. A combination of reverse video and color is a good choice to highlight information that will prevent launch because it provides a redundant way to draw attention to this important information.

8. Displaying Missile Progress

a. Alternative Approaches

There are two basic options when deciding how to display missile alignment status: textual or graphical. The process proceeds in eight modes, each having their own name. Previous versions of TWCS used a textual representation that listed the missile's alignment mode.

b. Solution and Discussion

Tullis (1988) showed that initially, graphical representations of simple systems, such as the missile alignment status, allowed for faster interpretation that narrative formats. However, as users became more used to both types of display, there was no difference in interpretation times. As the ECO displays should be usable at first glance a graphical display is the better choice. Also, a progress bar is widely becoming the standard metaphor for system task completion, an appropriate widget for displaying missile alignment progress.

9. VLS Layout

a. Alternative Approaches

A full size VLS launcher is has eight modules of eight cells each. Displaying the information for 64 launcher cells in a very limited display area does not allow for many alternatives. Any method that is chosen should accurately represent the physical layout of the VLS launcher.

b. Solution and Discussion

As the ECO displays are being added to an existing system, the best option is to display the VLS as it is in the parent system. However, the limited application area of the ECO displays will require slight modification to ensure the display fits in the display. The only significant change to make is to simply reduce the amount of whitespace in the display.

10. Representing Information About Cells and Modules With Faults

a. Alternative Approaches

The informational requirements dictate what information should be contained in the labels for each launcher cell. Displaying if a module or cell has a fault can be done by highlighting the cell or module in some way.

b. Solution and Discussion

To ensure that this display remains consistent with the rest of the displays, the method used to display a cell/module fault should be the same as the method used to display conditions that prevent missile launch. The label for any cell or module that prevents a missile launching from that cell or module will be reverse video with a red background and white foreground.

To show that a missile has been selected, a more subtle form of highlighting is required to keep the screen from appearing too cluttered. A form of graphical highlighting, such as a border around the cell's information, is one method to do this.

11. Plan Status Page Layout

a. Alternative Approaches

The informational requirements list a great deal of information that is needed for each active plan. It is obvious that if several plans are active the information required to be displayed will quickly fill the limited application area of the ECO display window. Therefore, some method of paging or scrolling through the list of active plans is required. Two possible methods of accomplishing this are push buttons or scroll bars.

b. Solution and Discussion

To display the required data for each plan, several informational groupings should be used. As discussed previously, each data item should be labeled. Some form of separator should be used between each plan's status to aid in interpretation.

The most consistent method to view the large numbers of active plans is to use a scroll bar. The data should be displayed within an X workspace and scrolled with the associated scroll bar.

F. INITIAL PROTOTYPE DISPLAYS

Figures 4 through 8 show the first iteration design of the ECO displays. These initial prototypes will undergo heuristic and guideline evaluation to discover any usability problems prior to interactive user testing.

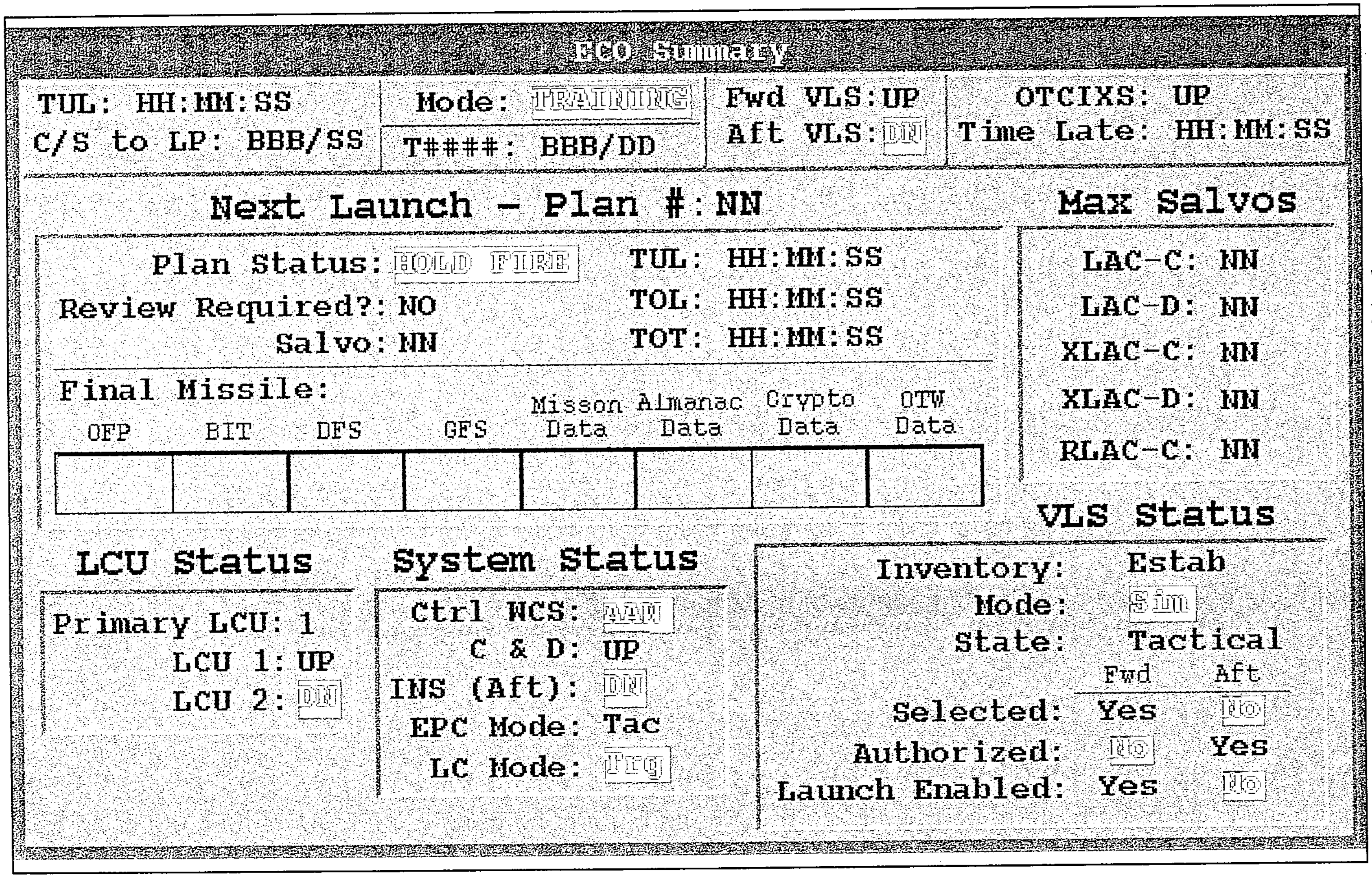

Figure 4. ECO Summary Display.

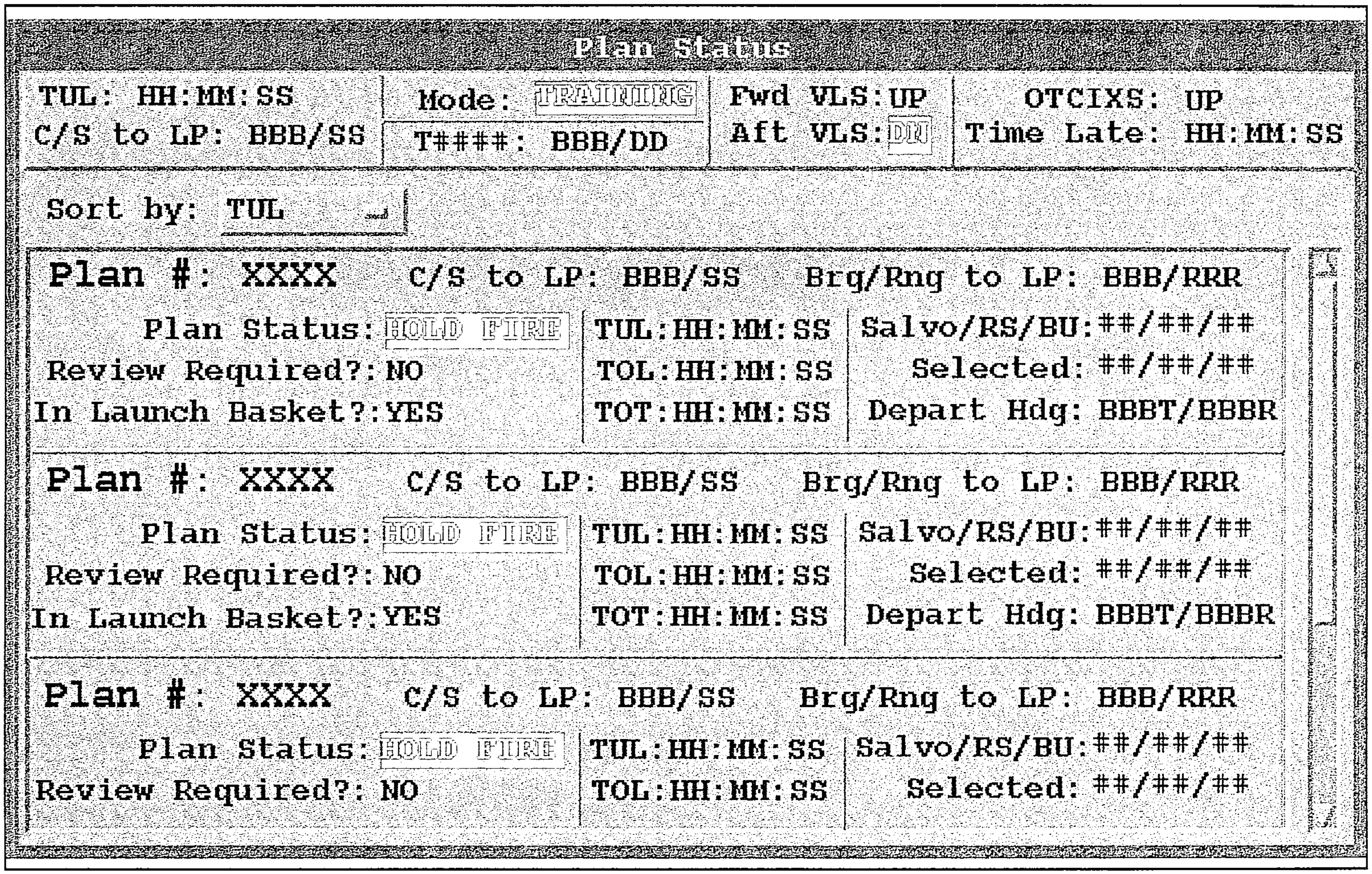

Figure 5. Plan Status Display.

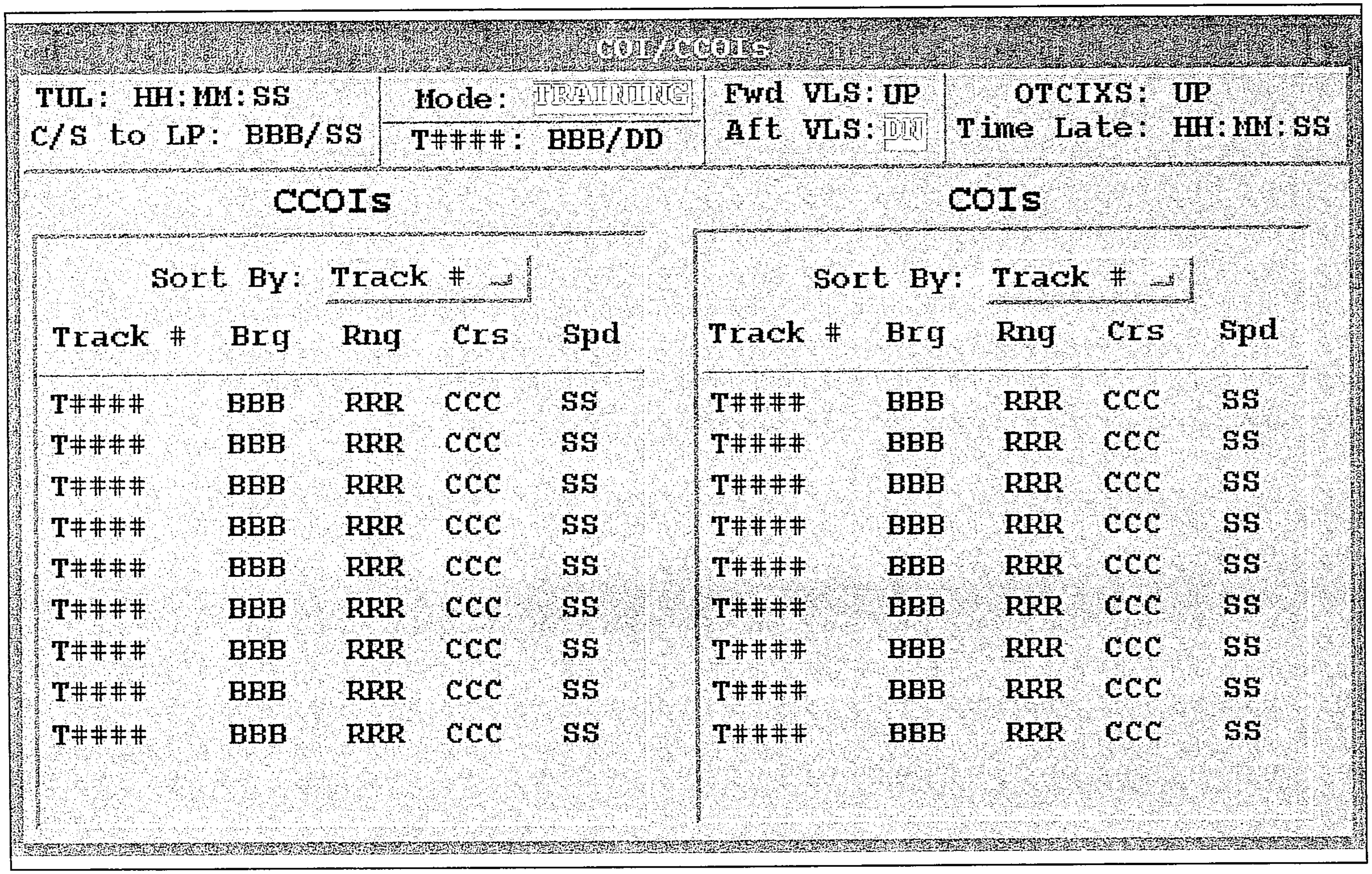

Figure 6. COI/CCOI Display.

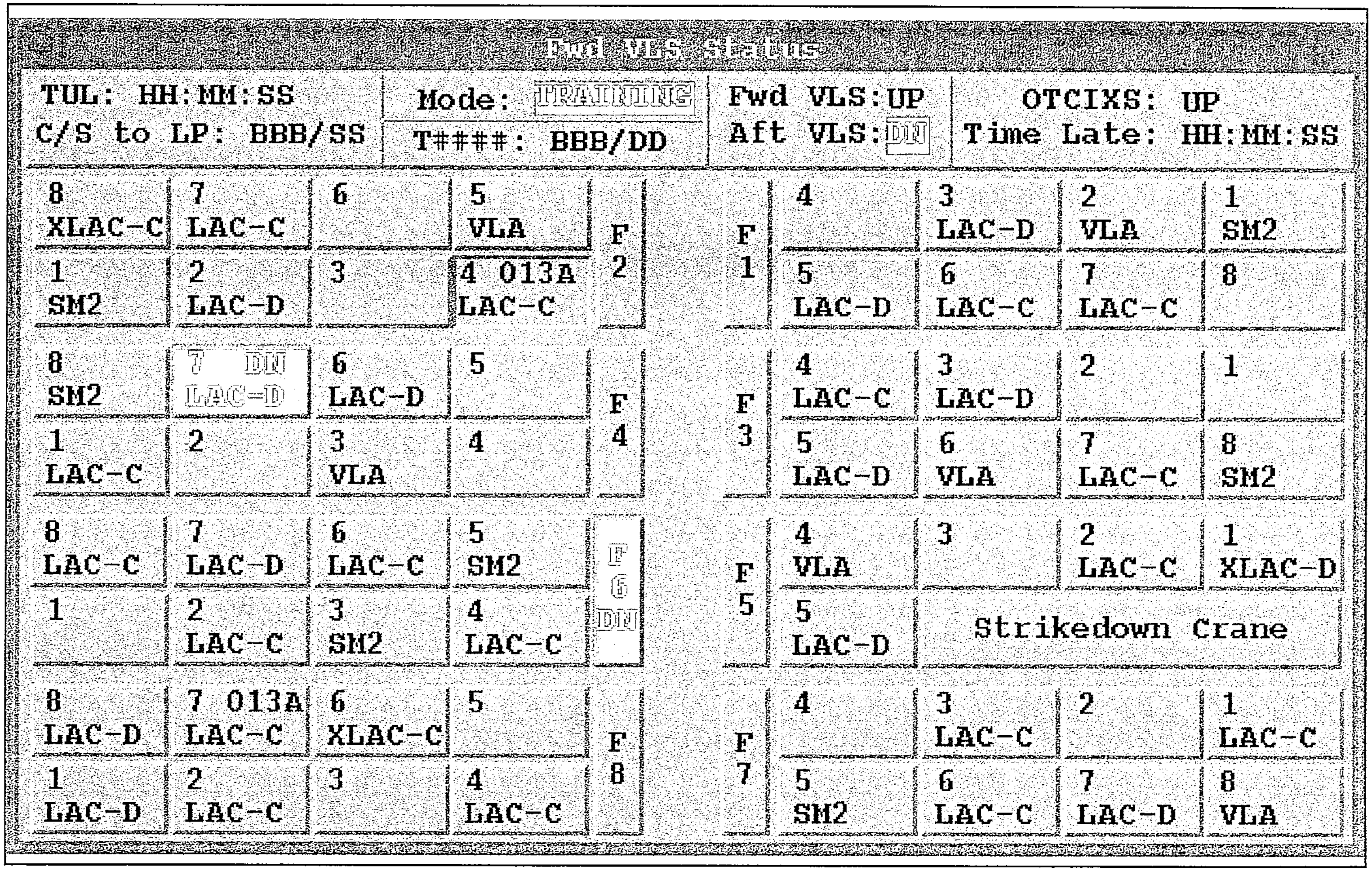

Figure 7. Forward VLS Display.

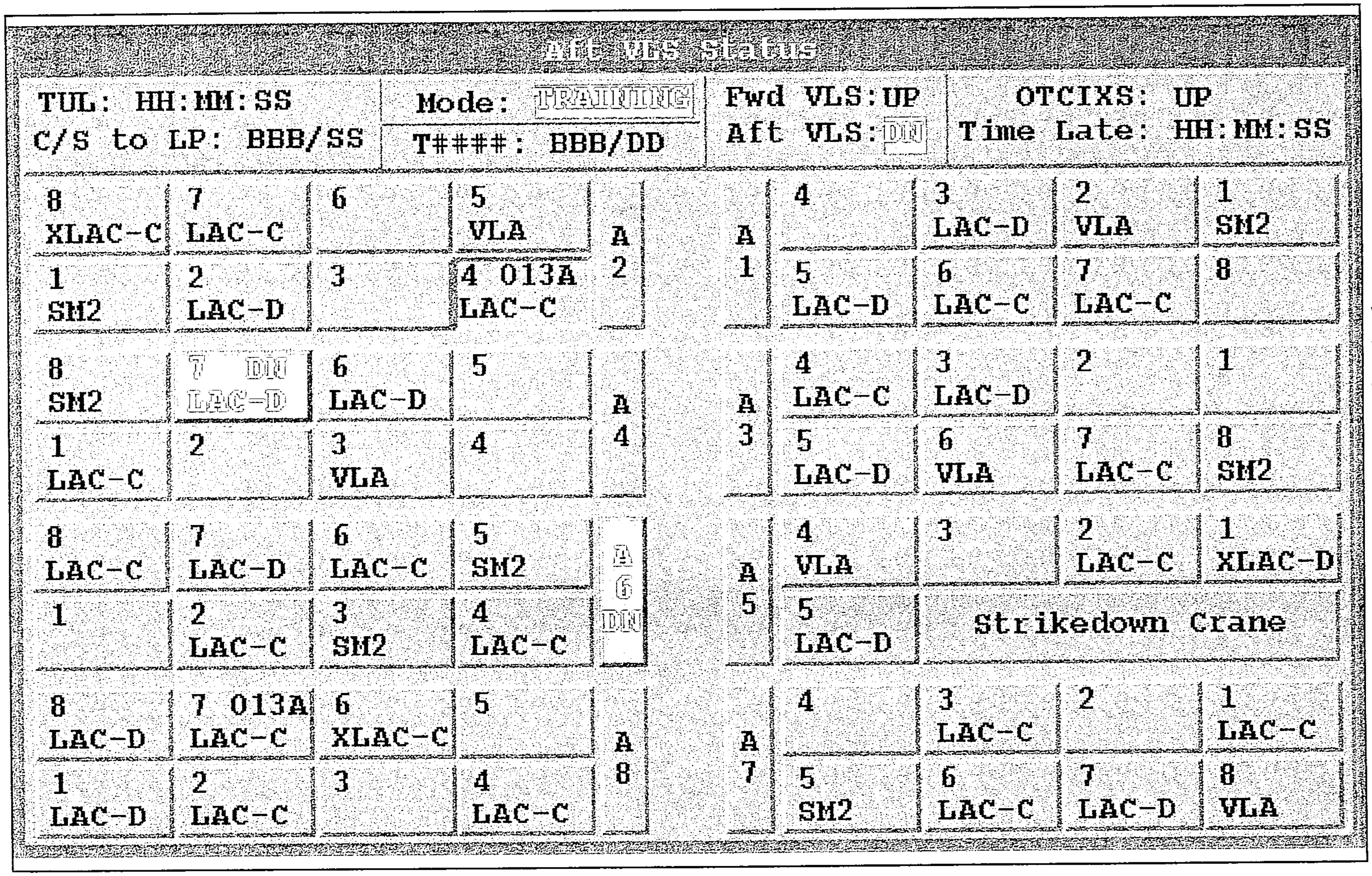

Figure 8. Aft VLS Display.

IV. HEURISTIC AND GUIDELINE EVALUATION

The are two general ways to test a user interface: with and without users. Both testing with users and testing without users may fail to reveal all the problems with an interface. A combination of the two methods, however, significantly improves the chances of uncovering all the usability problems in an interface (Lewis and Rieman, 1994). No matter which methods are employed, interface testing is critical to the success of an interface. Not only is there a cost savings associated with using interface testing methods, but there is increased usability as well (Nielsen, 1993). This increased usability is apparent through reduced errors, faster user response times and shorter user training times, all of which are essential to weapon systems (Nielsen, 1993).

Testing an interface with users can be expensive (Nielsen, 1993). It requires access to a group of test users that are as representative as possible of the intended users of the system (Nielsen, 1993). Sometimes, such users are not readily available or have their own time demands. Because of this, testing an interface with users requires a large amount of coordination between the testers and users and a great deal of prior preparation (Lewis and Rieman, 1994). Also, an interface is not normally ready to be tested by live users until it is nearly complete. Changes made to an interface at this stage in the lifecycle can be very costly to make (Nielsen, 1993).

From a time and cost standpoint, testing an interface without test users is relatively less inexpensive as it does not require advanced planning or a test user's time and effort (Nielsen and Molich, 1990; Lewis and Rieman, 1994). Testing an interface without users can be conducted early in the usability lifecycle to reveal problems that may hinder user testing. Problems uncovered at this stage of development are easier to correct as well (Nielsen, 1993).

This chapter discusses three methods of testing an interface without users: heuristic evaluation, guideline evaluation and cognitive walkthroughs. The methods are compared to other forms of user testing and two methods are applied to the initial

Engagement Control Officer (ECO) displays presented in Figures 4 through 8. The results of these analyses are listed and the resulting second iteration ECO displays are presented.

A. ANALYSIS METHODS

1. Heuristic Evaluation

Heuristic evaluation is an informal method of usability analysis where evaluators use their experience and a set of guidelines, called heuristics, to find usability problems with an interface (Nielsen and Molich, 1990). The goal of heuristic evaluation is to find usability problems in an interface so they can be resolved as part of the iterative design process (Nielsen, 1993). There are many lists of heuristics for interface evaluation. They range from very short, very general guidelines to lists containing thousands of very specific guidelines. Both approaches have their problems. Evaluations using very general lists often miss usability problems and the long lists are usually too unwieldy to apply (Lewis and Rieman, 1994).

a. A Set of Heuristics

Nielsen and Molich (1990) introduce a set of nine heuristics for to evaluating the usability of an interface. These heuristics were developed by Nielsen and Molich based on their experience teaching and consulting about usability engineering. The nine principles are generally accepted in the user interface community and are present either explicitly or implicitly in most lists of principles for human-computer interface (HCI) design (Lewis and Rieman, 1994). Each of the heuristics is discussed briefly below. A more thorough discussion of each heuristic can be found in Nielsen (1993).

- **Simple and natural dialog** - User interfaces should be as simple as possible, presenting only the information the user needs, and no more, exactly when it is needed (Nielsen, 1993). This information should be in an order that matches the user's task at hand (Lewis and Rieman, 1994). When graphical user interfaces are used, these concepts can be extended to graphical aspects such as color use and graphical boundaries.
- **Speak the user's language** - Since an interface is designed for a user, it should use terms that are based on the user's language. When users have their own specialized terminology for their domain, the interface should use it, rather than

more commonly used everyday language (Nielsen, 1993). System-specific engineering terms should be avoided. This concept is further extended to the use of metaphors in the interface. Any metaphors that are used should be correct mappings from the user's conceptual model and not present any dual meanings.

- **Minimize user memory load** - The user should not be made to remember information given by the interface. Information should be left on the screen until it is no longer needed (Lewis and Rieman, 1994). Also, the system should be built around a small number of rules that apply throughout the interface to make it easier to transition from one part to the next without having to relearn or remember such rules (Nielsen, 1993).

- **Be consistent** - Consistency applies to the way interface elements both appear and behave. If a user can apply an action in one situation and get a certain result, they should expect similar results when applying that same action in a different situation. This behavioral consistency lets users feel more confident when using the system as they will know what to expect when repeating the same action. The same information should be formatted in the same way on every screen to facilitate recognition. (Nielsen, 1993) This consistency in appearance can help reduce search times as a user becomes more familiar with an interface and knows where to expect certain information. More on consistency can be found in Tognazzini (1990).

- **Provide feedback** - The system should let the user know how it is reacting to their input at all times (Nielsen, 1993). Feedback should be timely and expressed in concrete and specific terms. Users should know the effects their actions are having on the system (Lewis and Rieman, 1994).

- **Provide clearly marked exits** - "The system should offer the user an easy way out of as many situations as possible." (Nielsen, 1993) Exits can be in the form of Cancel buttons, escape key sequences or an "undo" facility. However they are conveyed to the user, exits should be obvious, easily accessed and quick. They should not rely on the user's memory of an action but rather be labeled and always visible.

- **Provide shortcuts** - Experienced users should be provided with quick methods to accomplish tasks without having to view information they do not need (Lewis and Rieman, 1994). They should be able to go directly to a desired location in the interface without having to traverse lengthy menu hierarchies.

- **Good error messages** - A system should provide error messages that are clearly worded, precise, unintimidating and offer solutions (Nielsen, 1993). Systems should also provide for error recovery when appropriate.

- **Prevent errors** - A better option than having good error messages is to avoid error situations in the first place. This is done by recognizing error prone situations and either avoiding them entirely or providing a way for the user to proceed through the situation without causing an error. An example is to provide a list of available files to a user rather than have them type in a filename that might be invalid.

b. How to Apply Heuristics

Nielsen and Molich (1990) outlines the best way they found to apply heuristics to evaluate an interface. They conducted an experiment in which four groups of evaluators heuristically evaluated separate interfaces. The average proportions of known usability problems found were 51%, 38%, 26% and 20% in the four experiments (Nielsen and Molich, 1990). By analyzing the results of their experiment, it was discovered that if the usability problems found by individual evaluators were combined with those of other evaluators in the group, the overall number of distinct usability problems increased dramatically. These aggregates of evaluators can find significantly more usability problems as the number of evaluators increases, with a point of diminishing returns around the point of ten evaluators (Nielsen and Molich, 1990). Table 1 shows the average proportion of usability problems found in each of the four interfaces for various sized aggregates of evaluators.

	Number of Evaluators in Aggregate				
	1	**2**	**3**	**5**	**10**
Interface 1	51%	71%	81%	90%	97%
Interface 2	38%	52%	60%	70%	83%
Interface 3	26%	41%	50%	63%	78%
Interface 4	20%	33%	42%	55%	71%

Table 1. Average Proportion of Usability Problems Found for Various Sized Aggregates of Evaluators. After Nielsen and Molich (1990).

This data indicates that heuristic evaluation is best done with more than one person. However, even with only one evaluator, a fairly large number of problems can be found. When supplemented with another usability engineering method a large number of problems can be discovered with only one evaluator (Nielsen and Molich, 1990). Another way to increase the proportion of usability problems found with only one evaluator is to use a more experienced evaluator. An even greater number of problems can be discovered if the evaluator is also a "double expert," that is, the evaluator is experienced in the interface's domain as well as in interface design (Nielsen, 1993).

2. Guideline Evaluation

Guideline evaluation is a method of interface evaluation that uses very specific recommendations about the design of an interface. They usually include such recommendations as how the contents of a screen should be organized or how items should be arranged in a menu. The number of guidelines is usually very large. Guideline lists are normally specific enough to be applied by people unexperienced in user interface evaluation (Jeffries *et al.* 1991). This potentially increases the number of people that are able to conduct interface evaluation which is especially helpful when usability specialists are unavailable.

One example of a guideline list can be found in the Open Software Foundation's Motif Style Guide. It includes an 80-page Level One Certification Checklist that specifies how an application program must behave to be certified "OSF/Motif Style Guide Compliant" (OSF, 1993). Such a list can be invaluable to an interface developer to ensure a new interface complies with current standards and to point out possible usability problems associated with not following such standards.

3. Cognitive Walkthrough

Cognitive walkthroughs are a method of interface evaluation in which interface developers walk through the interface in the context of core tasks that a typical user needs to accomplish (Jeffries *et al.* 1991). The evaluation proceeds by first selecting a task that the interface was designed to support. The evaluator then attempts to accomplish the task by pretending to be a user who is new to the interface. For the method to work correctly, the evaluator must make good assumptions of what the user is thinking. While carrying out the task, if the evaluator cannot make a reasonable assumption based on his knowledge of the user and the prompts and information supplied by the interface, a usability problem exists (Lewis and Rieman, 1994).

This method is best suited for a task-centered user design methodology such as that described in Lewis and Rieman (1994). In such a methodology, the interface is designed to support a list of typical tasks which are specified during a task analysis. Walkthroughs focus most clearly on problems users will encounter when they first use an interface (Lewis and Rieman, 1994). Also, a cognitive walkthrough is really a tool for developing the interface, not validating it (Lewis and Rieman, 1994).

4. A Comparison of the Methods

Jeffries *et al.* (1991) experimentally compares four methods of testing an interface: heuristic evaluation, guideline evaluation, cognitive walkthroughs and usability testing. A single interface was evaluated by four teams, each using one of the above methods. Specific information about the background of the interface reviewers and the methods they used can be found in Jeffries *et al.* (1991).

After the completion of each evaluation, the errors they reported were analyzed. The evaluations uncovered 206 problems that addressed usability errors which were dubbed "core" problems. Heuristic evaluation uncovered 105 core problems with usability guidelines, cognitive walkthroughs and usability testing accounting for 35, 35 and 31 of the remaining 101 problems, respectively (Jeffries *et al.*, 1991).

Each core problem was also rated by the testers in terms of severity on a scale of 1 (trivial) to 9 (critical). These ratings took into account the impact of the problem, the frequency it occurred and the number of users that it would affect. (Jeffries *et al.*, 1991) Using these ratings, each evaluation method's mean problem severity was calculated.

Usability testing uncovered the most severe problems, on average, with a mean problem severity of 4.15. Guidelines, heuristic evaluation and cognitive walkthroughs found problems with mean severity of 3.61, 3.59 and 3.44, respectively (Jeffries *et al.*, 1991).

The experimenters further analyzed the results of the interface evaluations by calculating a benefit/cost ratio. The benefit was found by summing the severity scores of all the core problems while the cost is simply the number of man-hours spent on analysis. The benefit/cost ratio was determined using two methods. In the first, the time that evaluators using the guidelines and cognitive walkthrough methods spent becoming acquainted with the interface was included. The second ratio does not take into account this time because in a real world situation the interface's developers would be conducting these evaluations, therefore, this additional time would not be expended. Table 2 summarizes the results of the benefit cost analysis using the second method.

	Heuristic Evaluation	**Usability Testing**	**Guidelines**	**Cognitive Walkthrough**
Sum of severity scores	433	133	130	120
Analysis time (man-hours)	35	199	22	37
Severity/time	12	1	6	3

Table 2. Benefit/Cost Ratios for the Four Evaluation Techniques.
After Jeffries *et al.*, 1991.

This experiment shows that techniques for testing an interface without users are very cost effective, especially heuristic evaluation. However, many severe problems simply cannot be found without testing an interface with users (Jeffries *et al.*, 1991) . It also implies that a combination of usability testing techniques are the best way to find a wide range of usability problems.

B. ANALYZING THE INTERFACE WITHOUT USERS

1. Evaluation Methods Used

To test the ECO displays without users, two methods are employed: heuristic evaluation and guideline evaluation. These methods are used because of their high benefit/cost ratio and their ease of application. The combination of these methods can uncover a significant number of usability problems as shown by Jeffries *et al.* (1991).

The heuristic evaluation of the ECO displays is conducted by one person using the heuristics described in Nielsen (1993). Although the optimal way to conduct a heuristic evaluation is to use aggregates of evaluators, a single evaluator can uncover a significant number of usability problems (Nielsen and Molich, 1990). The results of a heuristic evaluation conducted by a single evaluator should not be the sole method for determining usability problems because, as shown in Nielsen and Molich (1990), a single evaluator can miss some usability problems. In order to uncover the maximum percentage of usability problems, single evaluator heuristic evaluation should be only one part of a usability testing plan.

The guidelines used to conduct the guideline evaluation are contained in Appendix B of JCM-2154. This 46-page checklist ensures that a user interface conforms to JCM-2154 standards. Each guideline represents a single HCI requirement from JCM-2154.

2. Results of Heuristic Evaluation

Heuristic evaluation of the ECO displays reveals nine usability problems. The small number of problems can be attributed to two reasons. First, the evaluation is conducted by only one evaluator and, for the reasons discussed previously, one cannot expect this method to uncover a large proportion of usability problems (Nielsen and Molich, 1990). Second, the ECO displays are very simple in terms of user interaction. The displays consist of only five display pages, only three of which have interface elements that can interact with the user. Table 3 describes each problem and its resolution.

Display Page	Heuristic	Problem Description	Problem Resolution
ECO Summary	Speak the user's language	Several labels are abbreviated incorrectly.	Change labels to more acceptable abbreviations.
ECO Summary	Be consistent	Position of information given for next launch is not consistent with the same data listed on the Plan Status Display.	Change information's position to the same as listed for each plan on the Plan Status Display
ECO Summary	Be consistent	Information about Salvo is not consistent with the information given on the Plan Status Display.	Change information given to "Salvo/RS/BU" to become consistent with Plan Status Display.
ECO Summary	Be consistent	Labels of groups are not consistent. "VLS Status" label is not centered over the group it labelled.	Move label to center of group.
ECO Summary	Be consistent	Labels of conditions signifying a launch is not possible are not consistent in their use of capitalization.	Change labels of all conditions that prevent launch to contain all uppercase letters only.
Plan Status	Simple and natural dialog	Violates the gesalt rules for human perception as described in Nielsen (1993). This decreases the user's ability to perceive relationships between interface elements.	Modify arrangement of information to improve group perception.
Plan Status	Be consistent	Method of setting off groups of data is inconsistent with that used on ECO Summary Display and COI/CCOI Display.	Change grouping method to that used on ECO Summary Display and COI/CCOI Display
Plan Status	Be consistent	Method of labelling groups is inconsistent with that used on ECO Summary Display and COI/CCOI Display.	Move group labels to a position centered above each group.
COI/CCOIs	Speak the user's language	Abbreviation for course, "Crs", is not the normal abbreviation used.	Change label to "Cse," a more standard abbreviation.

Table 3. Heuristic Evaluation Results.

3. Results of Guideline Evaluation

Using the guideline checklist in JCM-2154, seven guideline violations can be found in the ECO displays. Table 4 shows which guidelines are violated and the action required to correct the problem.

Display Page	JCM-2154 Guideline	Corrective Action
COI/CCOIs	When applications provide the capability to sort the contents of a multi-column list box the heading of each column shall seem to be a push button.	Remove "Sort by" option menu. Replace column labels with push buttons whose function is to sort the list by that column when pressed.
Forward and Aft VLS Status	A push button shall be used to initiate action.	Change the representation of each cell from a push button to a graphic box.
All	When a widget contains an error, its background shall remain IndianRed2.	Although this does not apply directly, to remain consistent with JCM-2154, change background color of conditions preventing launch to IndianRed2.
All	All text shall be of the Helvetica font.	Change font to Helvetica.
All	The title shall be centered in the title bar and presented in uppercase letters.	Change titles to uppercase letters.
Plan Status	Data groupings shall be indicated with blank space, separator lines, and/or different intensity.	Revise method of grouping information.
COI/CCOIs	If the window contains many rows and columns, a blank line shall be inserted after every third to fifth row and three spaces inserted between every column.	Add blank line in between every third data set.

Table 4. Guideline Evaluation Results.

4. Effectiveness of Heuristic and Guideline Evaluation

Because one cannot know in advance the number of usability problems an interface contains, it is unclear what proportion of the total problems heuristic and guideline evaluation uncovers. Further evaluation by additional or more experienced evaluators may reveal a larger number of usability problems (Nielsen and Molich, 1990). Changes made to the ECO displays based on the results of the heuristic and guideline evaluation will make the interface more consistent with both accepted HCI standards and JCM-2154 requirements (Lewis and Rieman, 1994). This will reduce chances of user error, increase the speed and accuracy of data assimilation and reduce training time for the interface (Nielsen, 1993).

C. SECOND ITERATION DISPLAYS

Figures 9 through 13 show the second iteration of the ECO displays. These will be subjected to user testing to reveal any further usability problems in the interface.

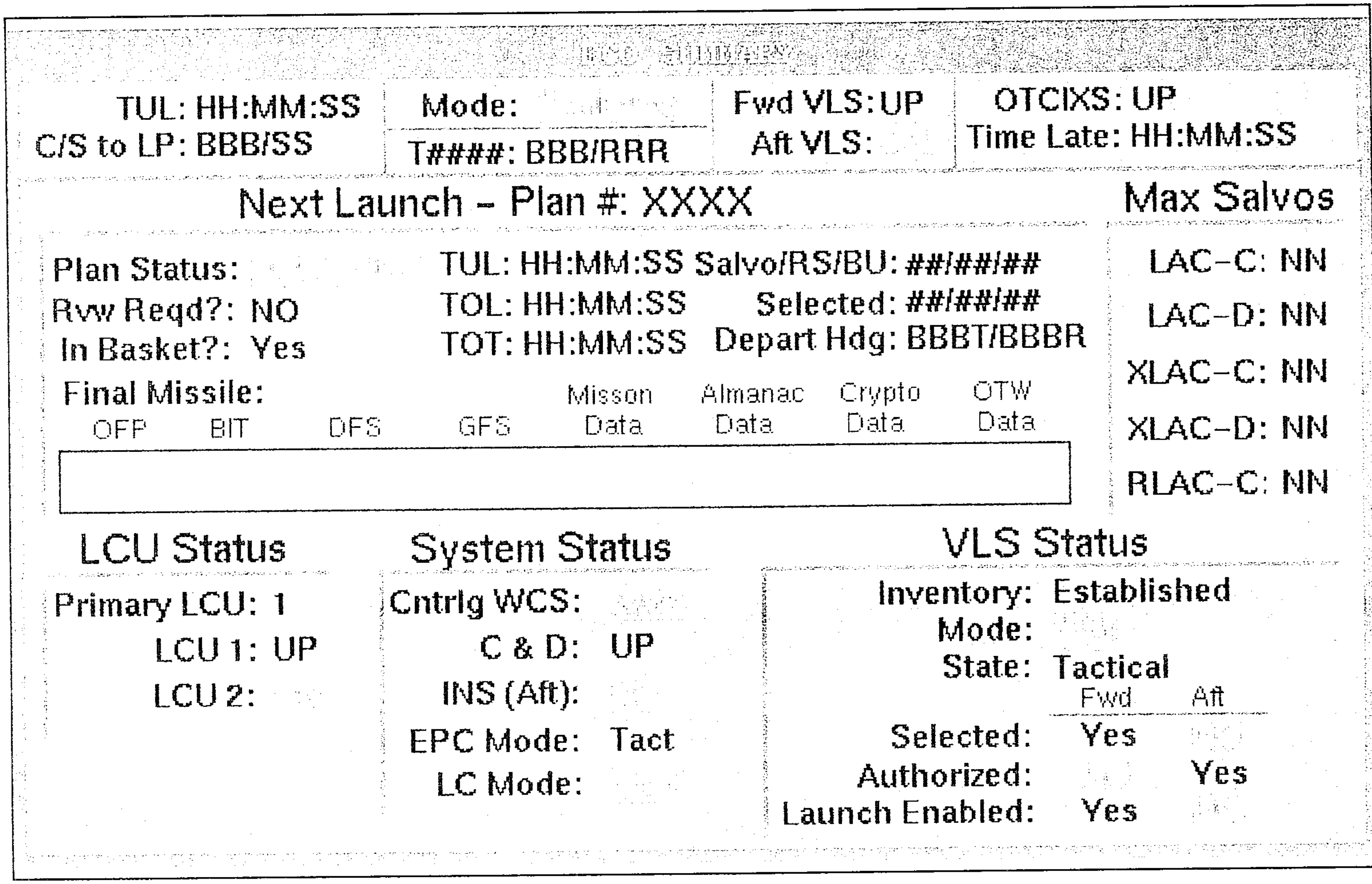

Figure 9. Second Iteration ECO Summary Display

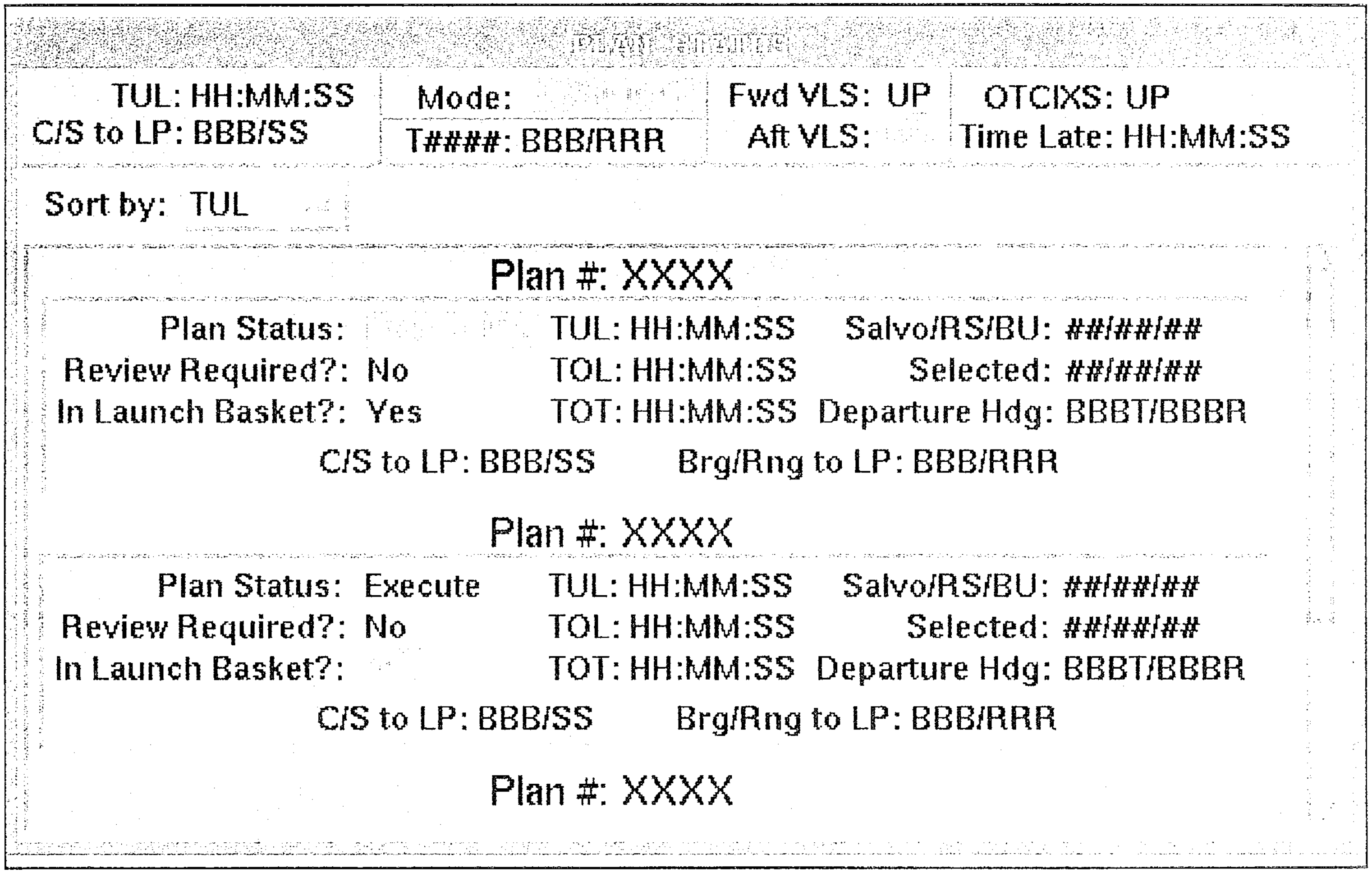

Figure 10. Second Iteration Plan Status Display

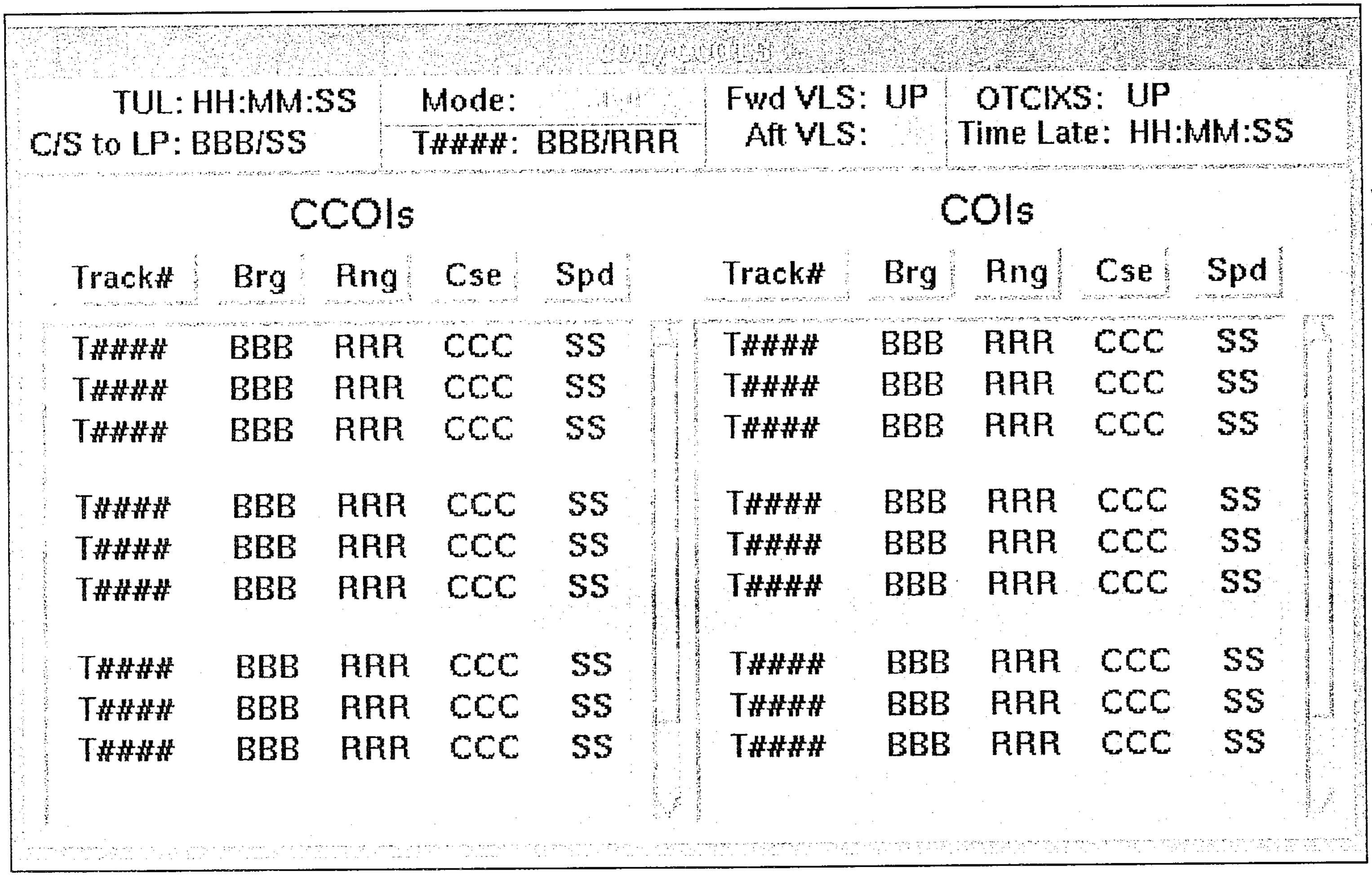

Figure 11. Second Iteration COI/CCOI Display.

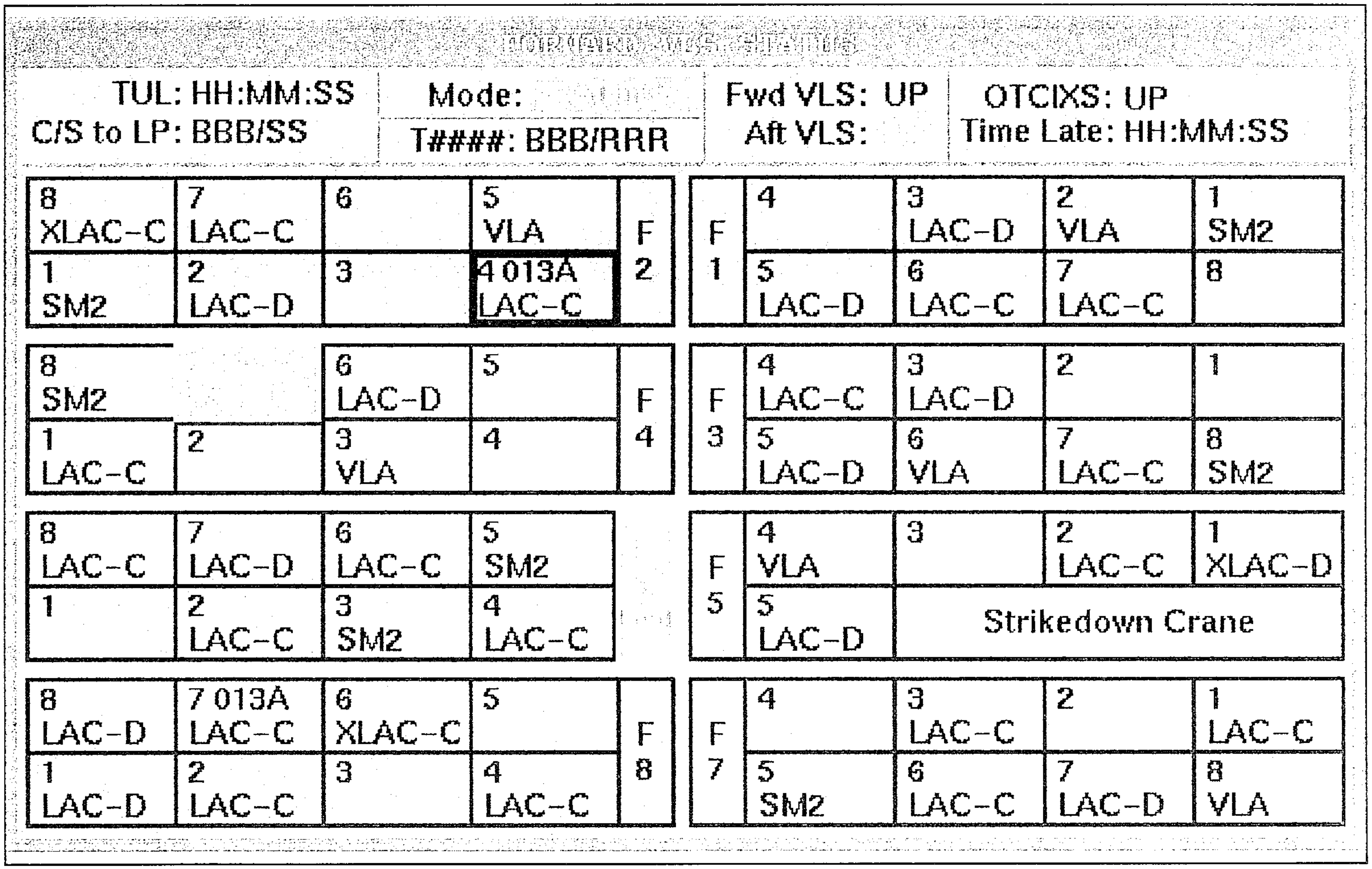

Figure 12. Second Iteration Forward VLS Display

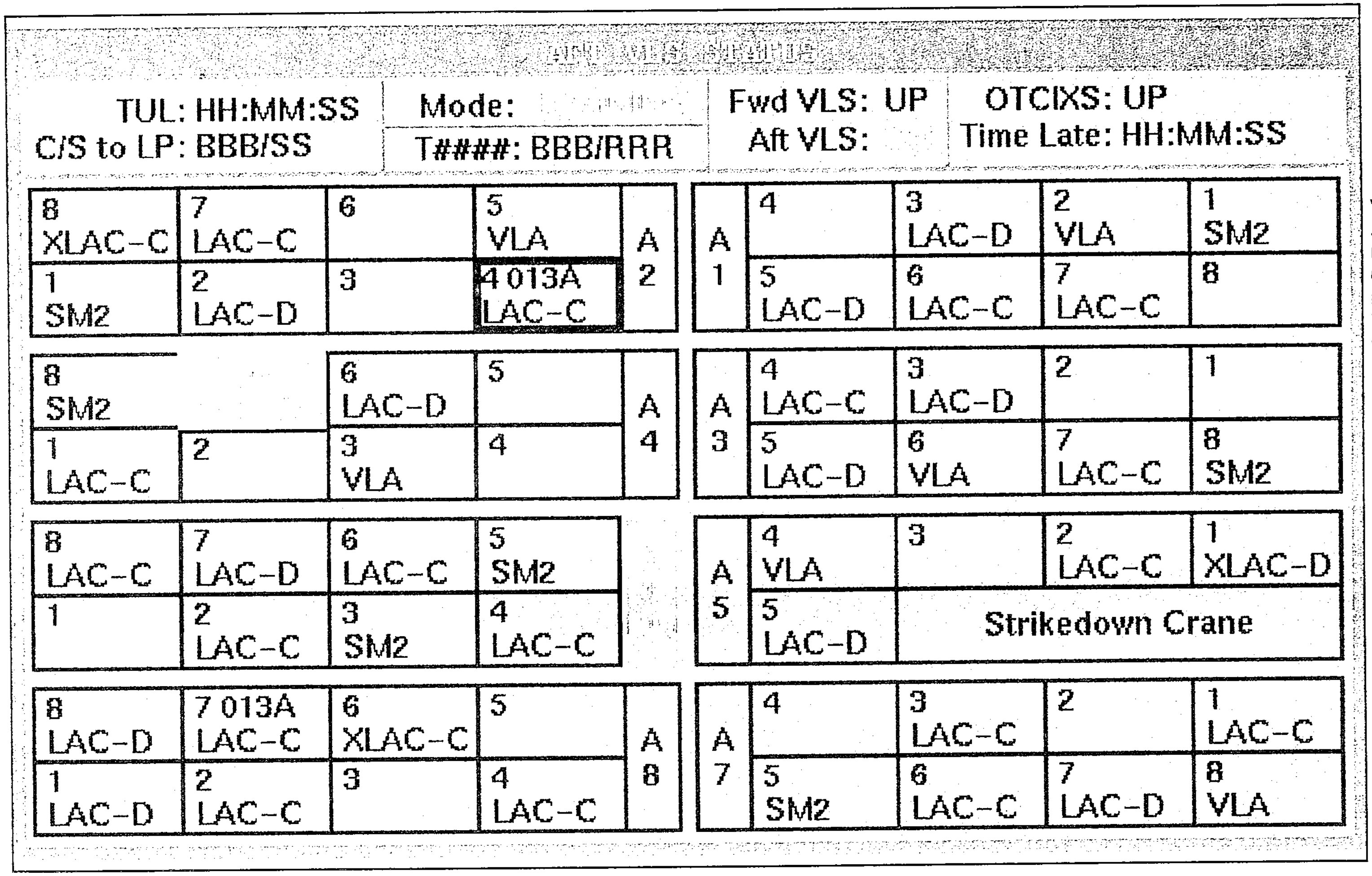

Figure 13. Second Iteration Aft VLS Display.

V. USABILITY TESTING

"You can't really tell how good or bad your user interface is going to be without getting people to use it." (Lewis and Rieman, 1994) Testing an interface with users is the most fundamental usability testing method because it provides the opportunity to find usability problems that can be missed by evaluation methods such as heuristic evaluation, cognitive walkthrough and guideline evaluation (Nielsen, 1993). Many of the most severe problems in a user interface simply cannot be found without using real users to test the interface (Jeffries *et al.*, 1991).

This chapter discusses some issues involved in usability testing. One method of usability testing, *thinking aloud*, is explored in detailed and the results of using this method on the Engagement Control Officer (ECO) displays is presented. Usability problems uncovered by user testing are then corrected and a set of third iteration displays is presented.

A. ISSUES IN USABILITY TESTING

1. Interface Test Users

Choosing users to test an interface can be as important as choosing a usability method to use. Test users should be as representative of the intended users of the system as possible (Nielsen, 1993). If the exact individuals for whom a system is being designed can be identified, then they should be used. If such users cannot be identified, subjects from closely related user populations might be acceptable subjects. For example, if a system is being designed for doctors, medical students may be good test users with more available time than practicing physicians (Lewis and Rieman, 1994).

Another issue when selecting test users is to account for both novice and expert users. Because of the disparity in their knowledge, novice and expert users should be tested with separate tests. These tests should contain common elements but also include different test tasks. (Nielsen, 1993)

There are also many ethical concerns when dealing with test users. Users must be made to feel comfortable and their emotions and well-being should always be kept in mind (Nielsen, 1993). Test users often feel a great deal of pressure to perform. Many times, a usability problem with an interface will cause a user to worry that they lack the ability or intelligence to use the system correctly. Users should be made to understand that it is the system that is being tested, not them. They should also be aware that their inability to perform a certain task is not a reflection on their ability, but rather the inability of the interface to provide them the means to accomplish it. (Lewis and Rieman, 1994) More on the ethical aspects of user testing can be found in Nielsen (1993) and Lewis and Rieman (1994).

2. Types of Data

Lewis and Rieman classify the data that can be collected during usability testing as either "process" data or "bottom-line" data. Process data are observations of what a test user is doing during the test step-by-step and, hopefully, why they are doing it. Bottom-line data are typically quantitative measurements taken during a usability test, such as the time a user takes to complete a task. (Lewis and Rieman, 1994)

Collection of process data is also know as formative evaluation. The main goal of a test using this form of data collection is to determine which aspects of a user interface are good or bad and to determine what changes should be made to a design. Formative evaluation is often done as part of the iterative design process and can be accomplished with only a few users. One usability testing method to use for formative evaluation is the *thinking aloud* test, discussed below. (Nielsen, 1993)

Summative evaluation is an attempt to assess the quality of an interface by collecting and analyzing bottom-line data. This form of evaluation is often done to compare two alternative interfaces or as a method to perform a competitive analysis. Measurement tests are typically used to perform a summative evaluation. In measurement tests, an aspect of the interface is given a quantifiable measurement that will be collected during the usability test. Nielsen (1993) lists several quantifiable usability measurements. This bottom-line data is recorded and analyzed to determine how well an interface meets expected usability goals or how one interface compares to another. The collection of bottom-line data takes a large number of user to ensure the data is both valid and reliable. (Nielsen, 1993)

3. Deciding on a Usability Method

Choosing a usability method can depend on many factors. But no matter which method is chosen, relying on the results of a single usability method to the exclusion of others is not recommended. Many usability methods can supplement one another because they address different parts of the usability lifecycle and the strengths of one method can make up for the weaknesses of another. (Nielsen, 1993)

Possibly the biggest factor that affects the choice of usability method is the goal of the test. One would not choose a qualitative or subjective test, such as *thinking aloud*, to validate a system because the opinions of a few test users may not reflect those of the actual target user group. Another factor that is closely related to the test goal is the stage of the usability lifecycle in which the test is conducted. Many methods, such as hueristic analysis, are best done early in the lifecycle while others, such as performance measurements, are more appropriate to the end of the lifecycle.

Another factor that drives the choice of which usability method to use is the number of test users available. When few users are available, it is best to concentrate on methods such as hueristic analysis and *thinking aloud*. Methods such as performance measurement require a large number of users in order to gather enough bottom-line data for the measurements to be considered valid and reliable. (Nielsen, 1993)

Table 5 summarizes the advantages and disadvantages of several usability methods. The table is necessarily simplified; however, Nielsen (1993) covers all the usability methods listed in detail. From Table 5 one can determine which usability method is best suited to a particular situation based on the usability lifecycle stage and number of test users available.

Method Name	Lifecycle Stage	Users Needed	Main Advantage	Main Disadvantage
Hueristic evaluation	Early design, "inner cycle" of iterative design	None	Finds individual usability problems. Can address expert user issues.	Does not involve real users, so does not find "surprises" relating to their needs.
Performance measurements	Competitive analysis, final testing	At least 10	Hard numbers. Results easy to compare.	Does not find individual usability problems.
Thinking aloud	Iterative design, formative evaluation	3-5	Pinpoints user misconceptions. Cheap test.	Unnatural for users. Hard for expert users to verbalize.
Observation	Task analysis, follow-up studies	3 or more	Ecological validity; reveals users' real tasks. Suggests functions and features.	Appointments hard to set up. No experimenter control.
Questionnaires	Task analysis, follow-up studies	At least 30	Finds subjective user preferences. Easy to repeat.	Pilot work needed (to prevent misunderstand-ings).
Interviews	Task analysis	5	Flexible, in-depth attitude and experience probing.	Time consuming. Hard to analyze and compare.
Focus groups	Task analysis, user involvement	6-9 per group	Spontaneous reactions and group dynamics.	Hard to analyze. Low validity.
Logging actual use	Final testing, follow-up studies	At least 20	Finds highly used (or unused) features. Can run continuously.	Analysis programs needed for huge mass of data. Violations of users' privacy.
User feedback	Follow-up studies	Hundreds	Tracks changes in user requirements and views.	Special organization needed to handle replies.

Table 5. Summary of Usability Methods. From Nielsen (1993).

B. THINKING ALOUD

A combination of usability methods that is often useful is heuristic evaluation and *thinking aloud*. First a hueristic evaluation is conducted to clean up the interface and correct any "obvious" usability problems. After redesign, the interface is subjected to user testing using the *thinking aloud* method to check the outcome of the iterative design step and to find remaining problems that were not discovered by the hueristic evaluation. (Nielsen, 1993)

> There are two major reasons for alternating between heuristic evaluation and user testing as suggested here. First, a heuristic evaluation pass can eliminate a number of usability problems without the need to "waste users," who sometimes can be difficult to find and schedule in large numbers. Second, these two categories of usability assessment methods have been shown to find fairly distinct sets if usability problems, meaning that they supplement each other rather than leading to repetitive findings. (Nielsen, 1993)

"*Thinking aloud* may be the single most valuable usability engineering method." (Nielsen, 1993) The idea behind *thinking aloud* is simple. A user is asked to complete a task and, while they work on it, they are to express their thoughts verbally (Lewis and Rieman, 1994). This usability method allows testers to understand how the user views an interface making it easy to identify any major misconceptions the user might have (Nielsen, 1993). The *thinking aloud* method has the advantage of being able to elicit a large amount of qualitative information from a small number of users. Its disadvantage is that it does not lend itself to any types of performance measurement. (Nielsen, 1993)

Lewis and Rieman (1994) describes many of the aspects of the *thinking aloud* procedure. These aspects are summarized in the following list:

- Instructions - The user should understand that the tester wishes to hear what they are thinking about while performing a task. They should understand that the interface is being tested, not them. (Lewis and Rieman, 1994)
- The observer's role - The observer should remain with the user to provide assistance if necessary. Users will not normally give a steady flow of comments unless prompted occasionally (Lewis and Rieman, 1994). The observer may

have to ask questions such as "What do you think that means?" when a user becomes confused to elicit constructive remarks. (Nielsen, 1993)

- Recording - Information can be recorded by taking notes on paper or may be accomplished by videotaping the test user. No matter how it is done, the goal is to record the users thoughts while performing an action.
- Summarizing the data - A list of all the problems the user had should be made. If possible, the reason why each difficulty arose should be added to the list. (Lewis and Rieman, 1994)
- Using the results - The results should be looked at from two aspects. First, does the data show that the interface worked as intended or did the users take different approaches than expected? Second, based on the user's difficulties, how important and difficult is each problem to correct?

C. USER TESTING AND RESULTS

1. Test Plan

User testing is carried out using the *thinking aloud* method. This method is well suited to test the ECO displays as they are still in the iterative design portion of the lifecycle and few test users are available. Users are instructed to describe their thought process while doing so. An observer is present to both record users' comments and assist the users only when necessary. The resulting data is summarized and subsequently used to make corrections to the ECO displays.

2. User Sketch

Three test users are all U.S. Navy officers with experience on board Tomahawk Land Attack Missile (TLAM) capable ships. All three users are qualified ECOs and one of the users has experience as Strike Warfare Officer, whose primary job is the maintenance and employment of the Tomahawk cruise missiles and their support systems. These test users are very representative of the users who would use the ECO displays during a TLAM strike.

3. Problems Found and Resolution

User testing using the *thinking aloud* method with three test users reveals eight additional usability problems. Each problem, the reason why it occurred and its resolution is listed in Table 6. The usability problems found in user testing are the basis for corrections to the second iteration prototype displays.

Display	Usability Problem	Reason for Problem	Resolution
All	The label for the nearest CCOI is confusing. Users are unable to determine what the label or information meant.	The label does not convey the proper information. In an attempt to save space, the label was shortened to be the track number of the CCOI. Users are unable to make the connection.	Debriefing with users found they do not feel the information is critical. The best solution is to remove the label.
All	The label for OTCIXS time late is misunderstood.	Improper terminology causes misinterpretation by the test users.	Change the label to "Last Data:"
All	Label for system status (Training/Tactical) is not obvious enough.	The label's position in the middle of the status bar keeps it from standing out.	Move system status to the left side of the status bar to make it more prominent.
Forward Vertical Launching System (VLS) Status and Aft VLS Status	Users are unable to determine which half modules are unavailable due to either a missile already being selected or a module fault.	Missiles that are unavailable for selection are not specified in any way.	Reduce the intensity of missiles that are unavailable for selection .
ECO Summary and Plan Status	Label for Salvo/RS/BU is misunderstood.	The "BU" portion of the label is not needed and causes confusion. A "back-up" mission is an operational concept and not something specified in the weapon system.	Remove "/BU" from label.
ECO Summary	Information for Controlling Weapon Control System (WCS) causes confusion.	The information does not represent the true state of the WCS switch.	Change information for Controlling WCS to read Off, Manual or Auto.
ECO Summary	Label for Inertial Navigation System (INS) causes confusion.	The INS is normally referred to by its equipment designator WSN.	Change label to read WSN instead of INS.

Table 6. Usability Testing Results.

Display	Usability Problem	Reason for Problem	Resolution
OSV Hierarchy	To change the page to one VLS status page while viewing the other requires too many keystrokes. Users prefer to switch back and forth between these two pages easily.	After selecting a VLS status page, the OSVs return to their original state. To switch to the other VLS status page requires selecting the 'VLS Status' button again and then pressing the OSV for the desired VLS status page.	When the user selects a VLS status page for display, the VLS Status OSV should be relabeled to the other VLS status page. For example, when viewing the Forward VLS Status page, the OSV would read "Aft VLS Status." This revised hierarchy enables fast switching between VLS status pages.

(Table 6 continued.) Usability Testing Results.

D. THIRD ITERATION DISPLAYS

The displays in Figures 14-18 are the third iteration of the ECO displays. These prototype displays can be used to conduct a summative evaluation to determine the effectiveness of the interface design.

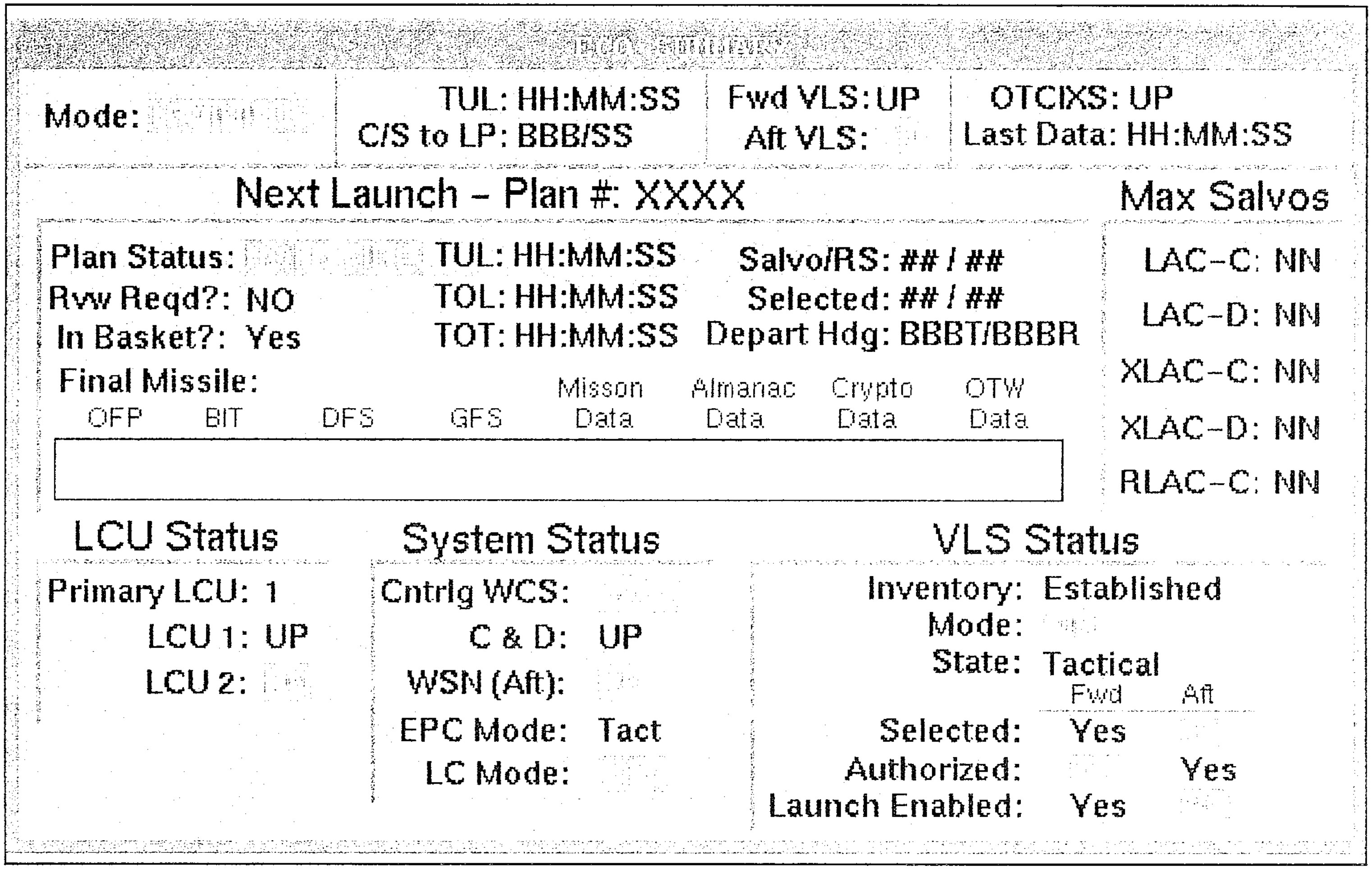

Figure 14. Third Iteration ECO Summary Display

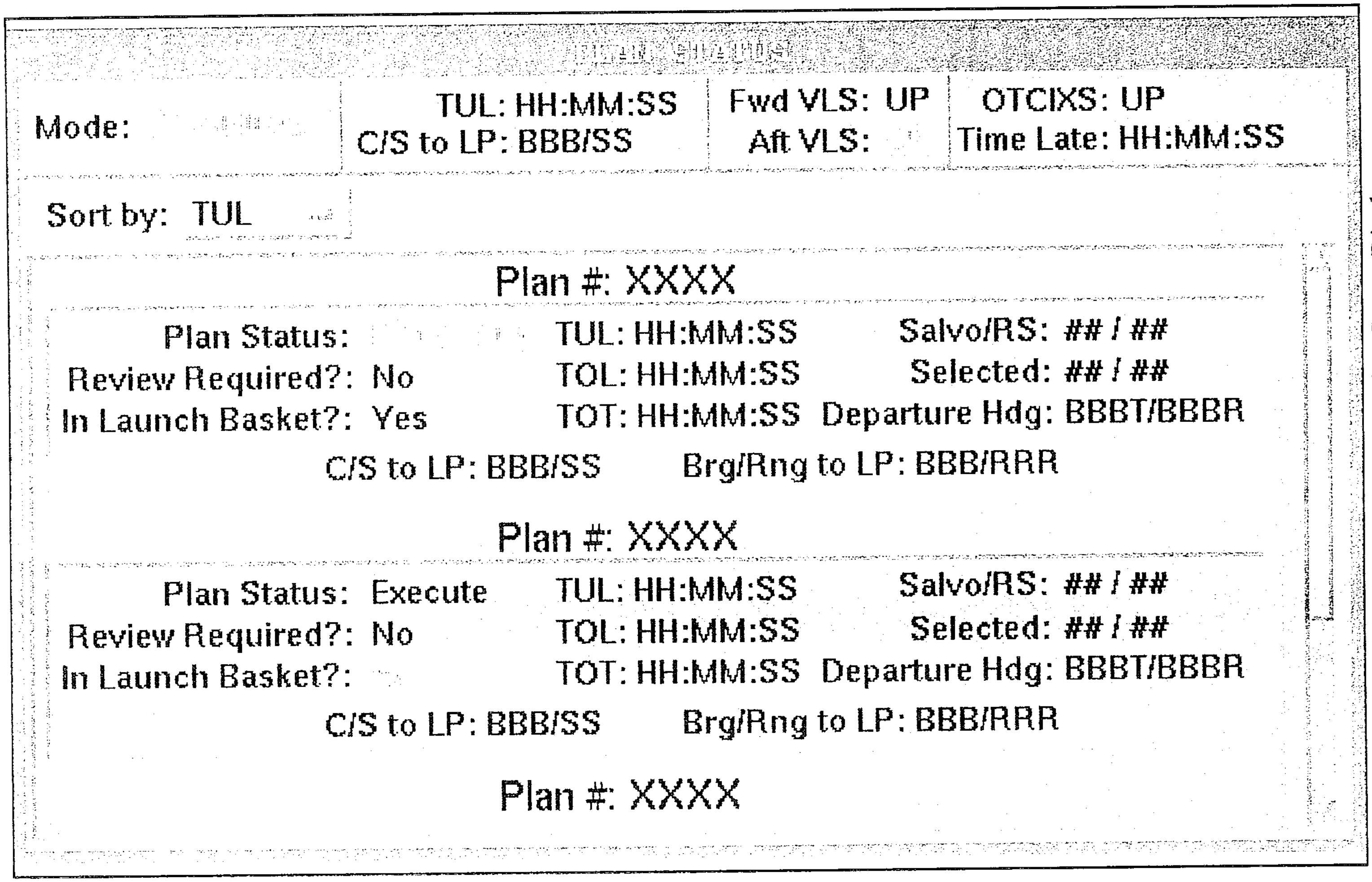

Figure 15. Third Iteration Plan Status Display.

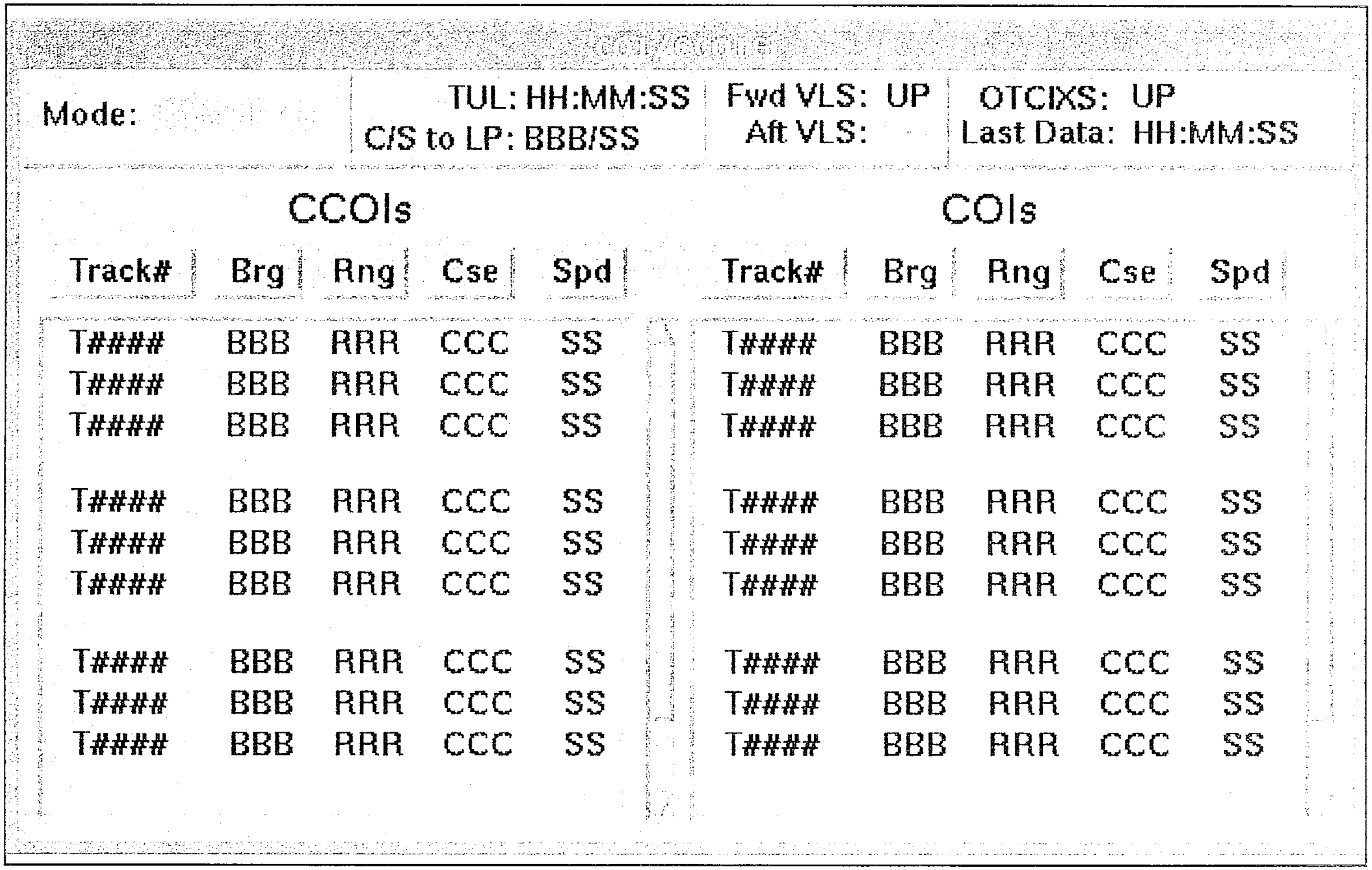

Figure 16. Third Iteration COI/CCOI Display.

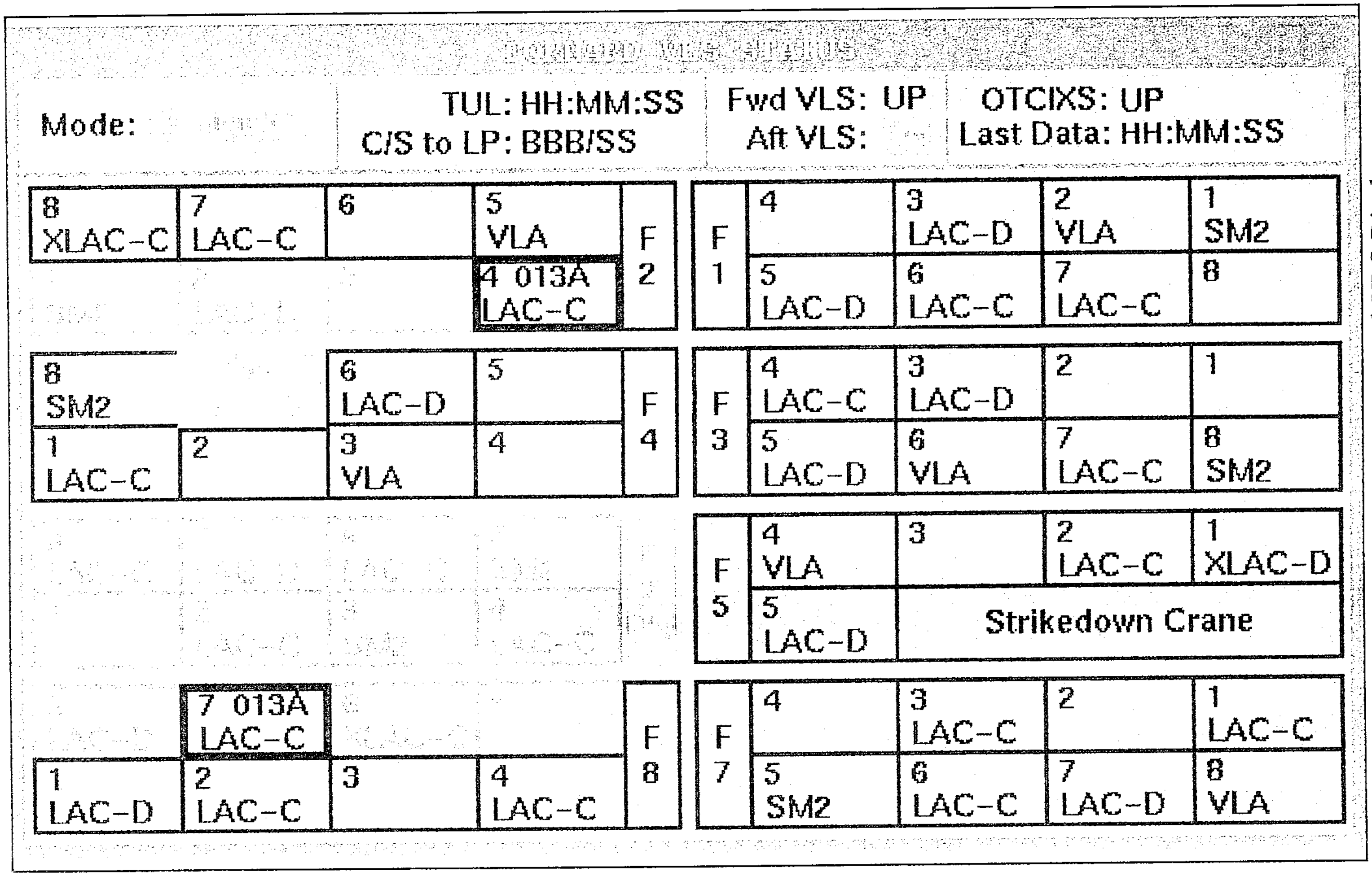

Figure 17. Third Iteration Forward VLS Display.

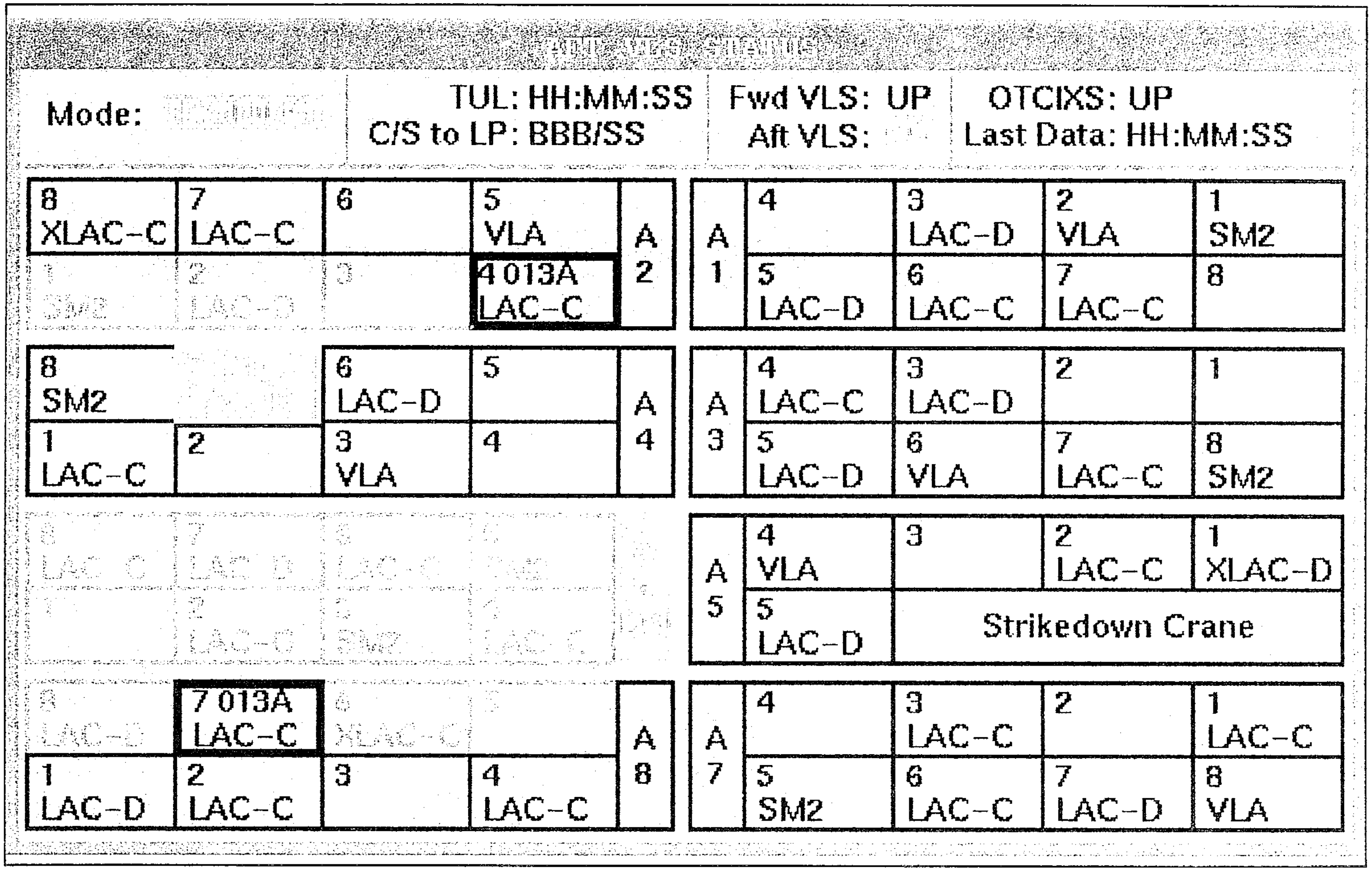

Figure 18. Third Iteration Aft VLS Display.

VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

Iterative interface design is an excellent method to produce a user interface that is focused on the needs of the user. Throughout the usability lifecycle, the interface design should be evaluated using an appropriate usability method. This ensures that usability problems are found as early as possible in the design process. This, in turn, enables usability problems to be corrected when they are easiest, and cheapest, to fix.

Assessing the usability of an interface does not necessarily require large numbers of test users or expensive usability testing laboratories. Methods such as heuristic and guideline evaluation provide a means to effectively evaluate an interface without the need for any users. They also have the advantage of requiring little preparation, making them easy to apply. The main disadvantage of evaluating an interface without users is that they are simply unable to replace the insights that a real user can provide. An excellent method of testing with real users is *thinking aloud*. This method of user testing reveals what a user is think about while using an interface. These insights are invaluable for correcting user misconceptions.

The Engagement Control Officer (ECO) displays are the result of applying an iterative design process. By employing usability methods early in the iterative process, usability problems in the displays are corrected before they become costly to fix. Testing the ECO displays with test user that are representative of the intended user group ensures that the displays meet user requirements and agree with user perceptions.

The ECO displays are a valuable addition to the Advanced Tomahawk Weapon Control System (ATWCS). The information that they present is necessary for the ECO to complete the mission of launching a successful Tomahawk Land Attack Missile (TLAM) strike. The system state and weapon status are accurately depicted to aid the ECO in making correct and timely decisions. By using sound screen design principles, the displays present the information in such a way that it can be read accurately and rapidly by the

ECO. Usability testing, both with and without test users, shows that the displays are consistent, use proper terminology and do not present information in a way that it could easily be misinterpreted.

B. RECOMMENDATIONS

The following list of recommendations are suggestions to improve the usability of the ECO displays. They also include recommendations to improve the usability of ATWCS for ECOs.

- Perform additional requirements analysis after the installation of ATWCS in fleet units - User perceptions and expectations may change after they become familiar with the capabilities of the new system. Additional requirements analysis will ensure that the users' needs are continuing to be met. A new requirements analysis will also reveal requirements that result from advances in Tomahawk Land Attack Missile (TLAM) technology.
- Increase the size of the secondary screen - The extremely small size of the secondary screen severely restricts the design of displays designated for this screen. A larger screen would increase the possible design alternative available for displays such as the ECO displays.
- Add remote displays to the hardware configuration of ATWCS - The nature of the ECO's responsibilities require that they remain standing during a TLAM strike, preventing them from sitting at a stationary console. Remote displays in addition to the secondary screen would allow the ECO to keep appraised of a strike's status without having to continually return to the ATWCS consoles. Along with this, the ECO could be provided some form of remote control to change the display shown on the remote screens.

C. SUGGESTIONS FOR FURTHER RESEARCH

Below is a list of areas that present opportunities for further research:

- Perform heuristic evaluation on the ECO displays with several more evaluators - As shown in Nielsen and Molich (1990), the number of usability problems found by heuristic evaluation increases significantly when aggregates of evaluators are used. These results could be compared to those found by a single evaluator to improve the ECO displays and further validate the findings of Nielsen and Molich (1990).
- Perform a summative evaluation of the ECO displays - Quantitative tests will uncover further usability problems and aid in the validation of the interface

design. Measurement tests could also be used to compare the ECO displays presented here with alternative designs.

- Perform a task analysis for the ECO displays - A task analysis would yield representative task that would need to be accomplished using the ECO displays. These tasks could be used to further refine the ECO displays and to perform additional usability testing using the cognitive walkthrough method.

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